TRICHODECTES CANIS, AN INVASIVE ECTOPARASITE OF ALASKAN WOLVES: DETECTION METHODS, CURRENT DISTRIBUTION, AND ECOLOGICAL CORRELATES OF SPREAD

By

Theresa M. Woldstad

RECOMMENDED:

Advisory Committee Chair

Chair, Wildlife Program
Department of Biology and Wildlife

APPROVED:

Dean, College of Natural Science and Mathematics

Dean of the Graduate School

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Date

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A

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Theresa M. Woldstad, B.S.

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ABSTRACT

Trichodectes canis, (Ischnocera: Trichodectidae), was first documented on Alaska gray wolves (*Canis lupis*) in 1981. Two hypotheses may explain why *T. canis* was not observed in Alaska until the 1980s. Symptomatic wolves could be predisposed to pediculosis, whereas mild infestations outside the observed infestation region are undetected by visual inspection. A second possible explanation is that *T. canis* is an invasive ectoparasite, and Alaska wolves outside the infestation region do not harbor lice. We examined wolf hides from December 2003 to February 2009, to investigate potential sampling locations, determine *T. canis* current distribution within Alaska, and investigate potential ecological correlates of spread. We determined that the caudal region of the wolf possessed the highest mean proportion of *T. canis* and we detected all cases of mild pediculosis. Lice were documented on wolves in a contiguous distribution from Southcentral Alaska to immediately north of the Alaska Range, (estimated area 174,000 km^2). Occult infestations were not detected outside of the current infestation zone. That pattern of occurrence suggests that *T. canis* is a novel parasite within Alaska. Ecological correlates positively associated with *T. canis* presence include wolf densities greater than eight wolves/1000 km^2 and mean annual January temperatures warmer than -19°C.

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Thesis Introduction

This thesis is the result of a four year study from 2005-2009, in cooperation with the Alaska Department of Fish and Game (ADF&G). Since *Trichodectes canis*, (Ischnocera: Trichodectidae), was first described on Alaska wolves of the Kenai Peninsula in 1981, potential management strategies and descriptions of current distribution were sought (Schwartz *et al*., 1983; Taylor and Spraker, 1983). To facilitate successful management strategies, my research addressed potential sampling methodologies, current distribution, and potential ecological correlates of lice presence for future management.

Trichodectes canis was first described on Alaska wolves of the Kenai Peninsula in 1981 (Schwartz *et al*., 1983; Taylor and Spraker, 1983). From November 1981 to March 1983, infested wolves exhibiting moderate to severe pediculosis (infestation of lice) were reported by Kenai Peninsula trappers to the ADF&G. During the winter of 1981, ADF&G inspected regional wolf packs for presence of *T. canis*; eleven wolves within four packs were found to be infected (Schwartz *et al*., 1983). In the winter of 1982, ten wolves within five packs exhibited clinical signs of pediculosis. Typical clinical signs observed include dandruff and hair loss (alopecia) of both guard hairs and under fur. All infested observed wolves possessed some degree of alopecia on the groin and trunk. However, most hair damage was moderate (Schwartz *et al*., 1983; Taylor and Spraker, 1983). In cases of severe itching (pruritus), the self-inflicted trauma often caused lesions, inflammation, and infected sores (Taylor and Spraker, 1983). Pups were more frequently infected than yearlings or adults, and exhibited higher levels of alopecia and lice density (Schwartz *et al.*, 1983; Taylor and Spraker, 1983). Typically, healthy individuals do not exhibit severe clinical signs of pediculosis as small infestations of ectoparasites within wild mammals are normal (Durden, 2001; Roberts *et al.*, 2002).

Infestation of *T. canis* within Alaskan wolves can have significant economic impact on the value of the fur. Active feeding of *T. canis* can result in moderate to severe pruritus; which can lead to barbing of the hair and alopecia. In addition, irritation from lice can cause sebaceous glands to exude excess sebum, resulting in seborrhea (excessive sebaceous gland secretions) and matting of the fur (Golden *et al.*, 1999; Mech *et al.*, 1985; Wall and Shearer, 2001). The mane of the wolf, which spans from the neck down to the shoulders and towards the center of the back, possesses the longer, more erectile guard hairs (Mech, 1970). This area is of particular value in terms of clothing ruffs. In cases of moderate to severe infestations, matting and alopecia are grossly apparent between the shoulders and can descend down the back, destroying the mane and the value of the fur (Golden *et al.*, 1999). Thus, pelts of heavily infested wolves typically cannot be salvaged for fur markets or for personal use.

After documenting *T. canis* occurrence among wild canids within the Kenai Peninsula, ADF&G considered several management options. In cases of early detection of invasive parasites, it is generally suggested to undertake eradication management for infested packs as this method is more economical and biologically feasible as compared to active treatment of all potentially exposed susceptible hosts. However, due to the high intrinsic value of wolves, ADF&G decided to implement active management by treating infected packs with the anitparasitic drug ivermectin (Taylor and Spraker, 1983). To determine the most practical method of treatment, three captive wolves were infested with *T. canis*; methods of administration were tested including oral treatments, use of impregnated baits, and intramuscular injection (Taylor and Spraker, 1983). Wolves were given twice the recommended dosage of ivermectin. It is important to note that ivermectin does not kill louse eggs; only the adult and nymph life stages are affected (Taylor and Spraker, 1983; Golden *et al*., 1999). However, it was found that levels of ivermectin within tissues remained at high enough concentrations to kill emerging lice (Golden *et al*., 1999). All three methods of treatment were found to be effective in treating pediculosis (Taylor and Spraker, 1983).

In March 1983, ADF&G treated wolves from five packs with ivermectin by intramuscular injections and impregnated baits scattered at sites of wolf kills (Golden *et al*., 1999). Despite ADF&G efforts, capturing and treating all infested wolves proved unsuccessful in eliminating the louse. Identification of mild and moderate pediculosis by visual inspection proved problematic, so some infested individuals may have been missed. In addition, success of treated baits was limited by restricted land coverage and consumption by non-target species (Golden *et al*., 1999). Based on these shortcomings, program funding stopped during the 1983-1984 trapping season (Golden *et al*., 1999). By the early 1990s, all known wolf packs within the Kenai Peninsula exhibited clinical signs of pediculosis, and *T. canis* continues to persist throughout the Kenai Peninsula (Golden *et al.*, 1999; Selinger, 2006).

After the spread of *T. canis* throughout the Kenai Peninsula, ADF&G attempted to confine the infestation to the peninsula. In the winter of 1991, two wolves with pediculosis were reported north of the Kenai Peninsula in the Knik River Valley (Golden *et al.*, 1999). ADF&G captured and treated wolves within the known infested packs with ivermectin. A later inspection of trapper-caught wolves showed that *T. canis* did not appear to have spread beyond the observed packs (Golden *et al.*, 1999).

In 1992, ADF&G funded a statewide study to determine the extent of pediculosis in wolves and coyotes. Wolves submitted for sealing under CITES by ADF&G were visually examined for *T. canis*. Of the inspected wolves, no evidence of pediculosis was found outside of the Kenai Peninsula (Golden *et al.*, 1999). However, reports of infested wolves and coyotes within the lower Susitna River Valley were documented in November and December of 1998 (Golden *et al.*, 1999; Peltier, 2006). Seven packs were examined east of the Susitna River in 1998, of which only one pack, within the Deshka River, was found to be infested with *T. canis* (Golden *et al.*, 1999). Additional funds were committed by ADF&G for the treatment of lice-infested packs when determined to be necessary (Golden *et al.*, 1999; Peltier, 2006). From December 1998 to March 1999, ADF&G captured and treated 40 wolves in ten packs from the Susitna River Valley. From visual inspection of the pelage, a total of 27 wolves representing three packs were infested with *T. canis* (Golden *et al*., 1999). In spite of treatment attempts, complete eradication of the lice from Alaskan wild canid populations proved to be infeasible (Peltier, 2006). If one animal escaped treatment, its pack would become reinfested, and would spread *T. canis* to adjacent packs. The long-term effectiveness of preventative management strategies using visual inspection and ivermectin treatment is currently unknown.

In 2004, *T. canis* was first documented north of the Alaska Range near Fairbanks, and in the Upper Kuskokwim River in 2005 (Young, 2006; Seavoy, 2006; Gardner and Beckmen, 2007). A monitoring program for *T. canis* has been recommended within the Fairbanks area to determine the transmission rate between wolf packs, the efficacy of ivermectin bait treatment for lice management, and the effects of pediculosis on productivity and survival rates of Alaska gray wolves (Gardner and Beckmen, 2008). In light of the previous management limitations, new strategies for *T. canis* management were sought. In general, severe to moderate pediculosis can be detected visually by trained personnel. However, a critical limitation of the Kenai and Susitna River Valley management strategies was the difficulty in detecting mild to moderate pediculosis, and subsequent treatment of all infested packs.

In 2005, an experimental mitigation management strategy was initiated by ADF&G south of Fairbanks. Utilizing a combination of visual examination, skin biopsy (tissue sample taken between shoulder blades), and potassium hydroxide (KOH) hide dissolution, Alaskan wolves were inspected for *T. canis* (Gardner and Beckmen, 2008). Hide dissolution utilizing KOH digestion of the entire host integument tends to be a more efficient and accurate method of lice detection as compared to visual or histopathology examination used previously (Watson *et al*., 1997; Clayton and Drown, 2001).

Hide dissolution can easily detect mild to moderate pediculosis, which is problematic when utilizing visual examination. However, complete dissolution of the hide is a time-consuming procedure that destroys the wolf pelt and potential lice voucher specimens. In addition, collection of the entire wolf pelt from trappers can be expensive. Thus, potential sampling strategies for *T. canis* detection were sought for various degrees of pediculosis within Alaska wolves.

Currently, it is unknown why wolves of the Kenai Peninsula and the Susitna River Valley exhibit high prevalence of moderate to severe pediculosis (Schwartz *et al*., 1983; Taylor and Spraker, 1983). In addition, it is unknown why *T. canis* has not been observed within Alaska until 1981 (Schwartz *et al*., 1983). Two hypothesizes may explain the observed high prevalence of pediculosis and apparent absence of *T. canis* in Alaska wolves until 1981. It is possible that *T. canis* is an endemic ectoparasite of Alaska canids, in which most individuals possess occult infestations that are not readily apparent by visual examination methods. Thus, observed symptomatic wolves are predisposed to pediculosis either inherently or by exposure to a secondary agent such as nutritional stress, age and suppressed immune response. A second possible explanation of the apparent absence of

T. canis from Alaska wolves is that lice are a recently introduced ectoparasite. Thus, wolves outside of the current infestation zone do not harbor lice in mild densities and observed infested individuals are unable to mount an effective response to *T. canis*.

The current distribution of *T. canis* is not ubiquitous across Alaska. Observed range expansion events have occurred sporadically since the first documentation of lice within Alaska wolves. Change in climatic conditions, such as warm temperature anomalies, has been shown to favor introduction events of invasive species (Desender *et al*., 1992; Desender *et al*., 2002). Temperature has been shown as an important limiting factor affecting fecundity and survival of chewing lice species (Ash, 1960; Moyer and Wagenbach, 1995; James *et al*., 1998). It is possible that warm winter temperatures could have facilitated *T. canis* introduction and sporadic range expansion in Alaska. Conversely, it is also possible that the observed sporadic range expansion is the result of chance and opportunistic wolf dispersal.

It is our objective to determine optimal sample locations on wolf hides for *T. canis* detection utilizing KOH hide digestion. In addition, our study assesses the current distribution of *T. canis* within Alaska and tests the hypothesis that *T. canis* occurs naturally in Alaska wolves and is present in low densities in areas not characterized by symptomatic wolves. Finally, we investigate potential ecological correlates associated with *T. canis* presence and spread within Alaska wolves, testing the hypothesis that the distribution of *T. canis* is temperature-dependent and constrained by low wolf densities.

Literature Cited

ASH, J. S., 1960. A study of the Mallophaga of birds with particular reference to their ecology. Ibis 102: 93-110.

CLAYTON, D. H., AND D. M. DROWN. 2001. Critical Evaluation of five methods for quantifying chewing lice (*Insecta: Phthiraptera)*. Journal of Parasitology 86: 1291-1300.

DESENDER, K., L. BAERT, AND J. MAELFAIT. 1992. El Niño - events and the establishment of ground beetles in the Galapagos Archipelago. Bulletin de l'Institut Royale des Sciences naturelles de Belgique Entomologie 62: 67-74.

__________, A. CASALE, L. BAERT, J. MAELFAIT, AND P. VERDYCK. 2002. *Calleida migratoria* casale, new species (Coleoptera: Carabidae), a newly introduced ground beetle in the Galapagos Islands, Ecuador. The Coleopterists Bulletin 56: 71-78.

DURDEN, L. A. 2001. Lice (*Phthiraptera*). *In* Parasitic Diseases of Wild Mammals. W. M. Samuel, M. J. Pybus, and A. A. Kocan (eds.). 2nd Edition. Iowa State University Press, Ames, Iowa, pp. 3-17.

GARDNER, C., AND K. BECKMEN. 2007. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1st July 2006-June 2007. Federal Aid in Wildlife Restoration. Grant W-

33-5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

__________, AND __________. 2008. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1st July 2007-June 2008. Federal Aid in Wildlife Restoration. Grant W-33-5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife conservation.

GOLDEN, H. N., T. H. SPRAKER, H. J. GRIESE, R. L. ZARNKE, M. A. MASTELLER, D. E. SPALINGER, AND B. M. BARTLEY. 1999. Briefing Paper on Infestation of Lice Among Wild Canids in Alaska. *In* Wolf management report of survey-inventory activities, M. Hicks (ed.). 1 July 1996-30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 98-112.

JAMES, P. J., R. D. MOON, AND D. R. BROWN. 1998. Seasonal dynamics and variation among sheep in densities of sheep biting louse, *Bovicola ovis*. International Journal for Parasitology 28: 283-292.

MECH, D. L. 1970. The Wolf's Wanderings. *In* The Wolf: The Ecology and Behaviors of an Endangered Species, D. L. Mech (ed.). University of Minnesota Press, pp. 149-167.

__________, R. P. THIEL, S. H. FRITTS, AND W. E. BERG. 1985. Presence and effects of the dog louse *Trichodectes canis* (Mallophaga, Trichodectidae) on wolves and coyotes from Minnesota and Wisconsin. American Midland Naturalist 114: 404-405.

MOYER, B. R., AND G. E. WAGENBACH. 1995. Sunning by Black Noddies (*Anous minutus*) May Kill Chewing Lice (*Quadraceps hopkinsi*). The Auk. 112: 1073-1077.

PELTIER, T. 2006. Unit 14 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 100-108.

ROBERTS, M. G., A. P. DOBSON, P. ARNEBERG, G. A. DE LEO, R. C. KRECEK, M. T. MANFREDI, P. LANFRANCHI, AND E. ZAFFARONI. 2002. Parasite community ecology and biodiversity. *In* The Ecology of Wildlife Diseases, P. J. Hudson, A. Rizzoli, B. T. Grenfell, H. Heesterbeek, and A. P. Dobson (eds.). Oxford University Press, pp. 63-82.

SCHWARTZ, C. C., R. STEPHENSON, AND N. WILSON. 1983. *Trichodectes canis* on the gray wolf and coyote on Kenai Peninsula, Alaska. Journal of Wildlife Diseases 19: 372-373.

SEAVOY, R. J. 2006. Unit 19 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 136-153.

SELINGER, J. 2006. Unit 7 and 15 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005.

Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 59-64.

TAYLOR, W. P., JR., AND T. H. SPRAKER. 1983. Management of a biting louse infestation in a free-ranging wolf population. *In* Proceedings: Annual Proceedings of the American Association of Zoo Veterinarians, M. E. Fowler (ed.). Tampa, Florida, pp. 40-41.

WALL, R., AND D. SHEARER. 2001. Lice (*Phthiraptera*). *In* Veterinary ectoparasites: biology, pathology, and control, 2nd Edition, Blackwell Science, London, pp.162-178.

WATSON, D. W., J. E. LLOYD, AND E. KUMAR. 1997. Density and distribution of cattle lice (Phthiraptera: Haematopinidae, Linognathidae, Trichodectidae) on six steers. Veterinary Parasitology 69: 283-296.

YOUNG, D. D. 2006. Unit 20A, 20B, 20C, 20F and 25C wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 154-165.

Chapter 1- Evaluation of *Trichodectes canis* detection methods in Alaska gray wolves[1]

Abstract: *Trichodectes canis*, (Ischnocera: Trichodectidae), was first documented on Alaska gray wolves (*Canis lupus*) on the Kenai Peninsula in 1981. In subsequent years, numerous wolves exhibited visually apparent, moderate to severe infestations. Currently, Alaska Department of Fish and Game utilizes visual inspection, histopathology examination, and potassium hydroxide (KOH) hide dissolution for *T. canis* detection. However, prospective sampling locations for *T. canis* on Alaska gray wolves are undefined. Our objective was to assess optimal sampling locations for *T. canis* detection. Wolves were subject to lice enumeration using KOH hide dissolution. Observed total body parasite loads ranged from mild infestations of 14 lice to severe infestations of 80,878 lice. The highest mean proportion of *T. canis* in sampled 100 cm^2 hide subsections was the back and was significantly different from the lowest mean proportion, found in the neck. However, 100 cm^2 subsections failed to detect all cases of pediculosis. We determined that a larger hide section from the caudal region, representing one-eighth of a hide, possessed the highest mean proportion of *T. canis* and was most sensitive for detection of lice for all cases of pediculosis. We recommend that KOH dissolution of the caudal region of the wolf be utilized for lice surveillance. However, the practical application of *T. canis* surveillance of hunter and trapper harvested hides utilizing large hide sections is limited.

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[1] Theresa M. Woldstad, Kimberlee Beckmen, Kimberly Dullen, and Kris Hundertmark. "Evaluation of *Trichodectes canis* detection methods in Alaska gray wolves." Prepared for submission to *Journal of Wildlife Diseases*.

Introduction

Trichodectes canis (Ischnocera: Trichodectidae), the common biting dog louse, is a host-specific ectoparasite of canids including the gray wolf (*Canis lupus*), domestic dog, and coyote (*Canis latrans*) in North America (Schwartz *et al*., 1983; Durden, 2001). The majority of the obligate life cycle of *T. canis* is spent within the pelage of the host (Durden, 2001; Wall and Shearer, 2001). Transmission typically occurs from direct physical contact between hosts, and use of common denning or bedding sites (Durden, 2001).

In 1981, *T. canis* was first documented on gray wolves in Alaska on the Kenai Peninsula (Schwartz *et al*., 1983; Taylor and Spraker, 1983). Those wolves exhibited high prevalence of moderate to severe pediculosis (lice infestation). In March 1983, the Alaska Department of Fish and Game (ADF&G) initiated a management program to eradicate *T. canis* infestation of wolves. The program attempted to identify and treat all infested wolves on the Kenai Peninsula utilizing visual examination, live-capture/release, and administration of the antiparasitic drug ivermectin (Ivomec®; Merial Limited, Duluth GA), (Taylor and Spraker, 1983; Zarnke, 1985). The program was unsuccessful due to difficulty in detection of mild pediculosis and the inability to conduct multiple treatments of infested wolves and coyotes (Masteller, 2000; Selinger, 2006). Since that time, the infestation has spread throughout southcentral Alaska and into interior Alaska north of the Alaska Range (Gardner and Beckmen, 2007).

At present, ADF&G uses a combination of visual inspection and skin biopsy from live wolves, histopathologic examination of representative skin samples, and KOH hide dissolution for detection of *T. canis* from deceased wolves. In general, the dissolution method of KOH hide dissolution of the entire host integument appears to have the highest sensitivity and specificity for lice detection as compared to visual or histopathologic examination (Watson *et al.*, 1997; Clayton and Drown, 2001). Hide dissolution is the most sensitive method to detect occult infestations with as few as four lice per wolf (ADF&G unpublished data). However, complete KOH hide dissolution is a time-consuming procedure that destroys the wolf hide and integrity of lice specimens. In addition, it is costly to obtain marketable wolf hides from trappers.

It would be advantageous if wolf hides could be inspected for *T. canis* by examining a smaller, well-defined region when using this sensitive but destructive technique. Rather than destroying the entire hide, if a skin sample could be taken from a region that is consistently infected but not of high market value, this method could be utilized for surveillance of hunter and trapper harvested hides with limited objection. Currently, optimal sample locations for *T. canis* detection within gray wolves are undefined. In addition, it is unknown if severity of pediculosis influences prime sample locations. While moderate to severe pediculosis can be detected by a trained individual through visual examination, mild pediculosis can be easily overlooked. Our objective was to determine optimal sample locations for *T. canis* detection within Alaska gray wolves utilizing KOH hide dissolution.

Materials and Methods

Wolf hides and whole carcasses collected by ADF&G and US National Park Service (NPS), and those donated by or purchased from trappers were inspected for *T. canis*. Pelts obtained from trappers were raw or dried and/or salted. Gross patterns of pediculosis, including hair loss and skin lesions were described. *Trichodectes canis* specimens were collected from raw wolf pelts, and stored in 80% ethanol. Lice specimens are archived at the University of Alaska Museum of the North under catalog number UAM 100019480. Samples of other incidental ectoparasites of prey species and non-parasitic arthropods such as oribatid mites were collected and identified.

Detection and enumeration of *T. canis* utilizing KOH hide dissolution was conducted using a modification of the method of Welch and Samuel (1989). From each thawed, fresh, or dried hide, the head was removed immediately behind the ears, the front legs were removed at the elbow, back legs at the hock, and tail at the base. The remaining hide was cut along the midsagittal plane, producing left and right sections (Figure 1.1). Each of the halves was then fleshed to remove the subcutaneous muscles and fat. A chalk-line was used to mark the hide into four relatively equal sections from cranial to caudal ends (Figure 1.1). Section one represented the most cranial section including the neck area. Section two corresponds to the region of the hide caudal to section one. Section three was caudal to the midpoint of the dorsal midline, and comprised most of the lumbar area. Section four was the most caudal region of the hide, and comprised the sacral area and groin. Each of the subdivided sections were labeled with the corresponding section number and wolf identification number on a laundry tag, placed in a plastic bag, and stored at -20 C.

When restrictive sampling based on pelt area was to be conducted, each section was further subdivided into smaller pieces approximately 10×10 cm (Figure 1.2). Sections were numbered from the cranial to caudal end and excised. Four subdivided hide pieces were utilized from each sampled wolf, including one piece from the neck, shoulder, back and groin regions (Figure 1.2). Each 100 cm^2 section was stored separately in plastic bags at -20 C until processed.

Individual hide sections were digested separately in a 5% KOH solution in stainless steel pans for large sections and 1L Erlenmeyer flasks for 100 cm^2 sections. The solution was composed of 2400 mL of tap water, 110.9 g KOH, and 15 mL of liquid Dawn® detergent (The Procter and Gamble Company; Cincinnati, Ohio) as a degreasing agent. Sufficient solution to completely submerge the individual hide section was added and then incubated at 65-75°C and stirred at least once every thirty minutes for three to four hours until most of the hair and epidermis was dissolved, leaving a semi-transparent dermis and the exoskeletons of lice. The length of the incubation period varied with size of the section, fur density, and the thickness of the dermis. Post-incubation, the contents were filtered though a 180-µm sieve to retain lice and remaining dermal tissue followed by a warm tap water rinse to remove residual KOH. A second degreasing step was conducted at this stage when fatty deposits were observed within the sieve. The material retained by the sieve was washed into a 1L flask, covered with tap water, and sealed by Parafilm®

(Structure Probe Inc; Chicago, Illinois), and held up to 48 hours at room temperature until examination. Samples were drained again using a 180-µm sieve and examined under a dissecting microscope at 40× magnification.

A wolf was recorded positive for lice infestation if adult lice, larval instars or eggs were observed. Adult lice and larval instars were enumerated, and voucher specimens of exoskeletons were stored in 100% ethanol. Severity of pediculosis was classified based on parasite loads of active life stages for each half hide split down the dorsal midline of the body. Moderate to severe pediculosis can typically be detected by close visual examination. However, mild infestations can easily be overlooked. For the purpose of our study, cases of moderate to severe pediculosis were analyzed together representing heavy infestations as compared to mild pediculosis. Mild pediculosis was classified as less then 200 total lice per half hide and heavy pediculosis greater than 200 total lice per half hide. Due to the disparity between absolute numbers of lice for heavy and mild parasite loads, each section total was expressed as a proportion of the total left or right side. Lice proportions were normalized using arcsine-root transformations prior to statistical analysis. For 100-cm^2 subsamples, section totals was expressed as the density of the active life stages of *T. canis* of all four subsections obtained from the neck, shoulder, back and groin (Figure 1.2). Severity of pediculosis was classified as: mild (< 0.5 lice per 100 cm^2) and heavy (> 0.5 lice per 100 cm^2).

The statistical program JMP (SAS Institute Inc.) was employed for analysis of optimal sample locations for *T. canis* utilizing KOH hide dissolution. A two-way analysis of variance (ANOVA) was used to determine if proportions of lice among the four hide sections differed significantly. Multiple comparisons were assessed with the Tukey Honestly Significant Difference (HSD) test (Sall and Lehman, 1996). To determine if the degree of pediculosis influenced distribution of lice on the body, a two-way ANOVA was conducted separately for hides based on the degree of pediculosis.

Results

Complete or whole carcasses of 120 wolves were obtained from December 2003 to February 2009. Thirty-nine wolves were found to be positive for *T. canis* whereas 94 were negative for lice as determined by KOH hide dissolution. Of the 39 lice-infested wolves, 16 were subject to sectional lice enumeration. Five wolves were completely digested including both the right and left sides. Eleven wolves were partially digested including either the entire left or right side. Of the 16 examined wolves, eight possessed mild pediculosis and eight possessed heavy pediculosis.

We used the five completely digested wolves to compare proportion of lice on left versus right complete sides utilizing a matched pairs analysis. Proportion of lice for each side did not differ significantly between the left and right sides ($t = 1.14$, $P = 0.318$). For the purpose of our study, left and right sides of the wolf pelt were considered identical for analysis.

A total of 48 100-cm^2 hide sections was analyzed. The ANOVA indicated that the lice proportions did not significantly differ between mild and heavy pediculosis ($F = 0.716$, $P = 0.548$). As no significant effect between proportion of lice and severity of pediculosis was found, for the purpose of our study mild and heavy pediculosis was grouped together for analysis.

The ANOVA indicated that mean proportion of active life stages of *T. canis* was significantly different between 100 cm^2 hide subsections ($F = 3.70$, $P = 0.0185$). The highest mean proportion of active life stages of *T. canis* was the back subsection, which was significantly different from the neck, which exhibited the lowest mean proportion of *T. canis* (Table 1.1). It is important to note that none of the four 100 cm^2 hide subsections were able to detect *T. canis* on 100% of the sampled wolves (Table 1.2). The back subsection, with the highest mean proportion of lice, failed to detect lice for three samples, exhibiting the lowest detection probability (Table 1.2).

In addition to the 100 cm^2 subsamples, a total of 84 large hide sections was analyzed using a one-way ANOVA, representing a sample size of 21 for each hide section. Proportions of lice among the four body sections differed significantly ($F = 6.7$, $P = 0.0004$). The lowest mean proportion of lice was section one (0.41) and the highest mean proportion of lice was section four (0.64), (Table 1.1; Figure 1.1). Mean proportion of lice for hide section four was found to be significantly different from the remaining hide sections (Table 1.1). It is important to note that for hide sections three and four, none of the 21 samples of infested wolves showed absence of lice, and all cases of pediculosis were detected. For hide sections one and two, there was one infested wolf for each in which *T. canis* was not detected. Thus for detection of pediculosis, hide section four could be a potential sampling locations for *T. canis* detection on Alaska gray wolves.

Discussion

This study suggests that the optimal sample locations for *T. canis* detection, based on mean proportion and high detection probability, is the caudal region of the wolf. It is likely that the low rate of false-negative results obtained from the large hide section of the rump as compared to the 100 cm^2 subsections of the back simply reflects a difference in the size of the examined hide section (Table 1.2). Thus, to accurately detect *T. canis*, the selected sample area should be increased from 100 cm^2 to roughly one-fourth of the animal's length to have the sensitivity to detect all cases of mild pediculosis.

However, large hide samples would not be acceptable for hunter- or trapper-owned hides as this would still destroy a significant portion of the market value of a hide. Thus, 100 cm^2 samples from hide locations of low market value are likely to be more acceptable to hunters and trappers for *T. canis* surveillance. The mane of the wolf is of particular value to Alaska trappers due to its extensive use as traditional parka ruffs and generally will not be acceptable for any sampling (Harper, 2006). While the back possessed the highest mean proportion of lice, it also possessed the lowest detection probability for the 100 cm^2 samples (Table 1.1; Table 1.2). In comparison, the groin possessed the second highest mean proportion of *T. canis* and was not significantly different from the back section. In addition, the groin also possessed a higher detection probability as compared to the back. The groin also possesses low market value and low fur density, so lice and the skin lesions such as papules are more readily visible than on the thickly furred areas of the body. Requesting or requiring the submission of a 100 cm^2 section of the groin area is likely to be the only surveillance sample location that would be generally acceptable by hunters or trappers to preserve the market value of a wolf hide while having a relatively low false-negative rate.

The development of sensitive and repeatable sampling techniques for lice detection is the first step towards describing basic information of *T. canis* and development of successful management strategies. Several studies have shown that lice tend to possess a clustered distribution, in which species of chewing lice are clumped within specific areas of the host (Watson *et al.,* 1997; Milnes *et al.,* 2003). Our results demonstrate that *T. canis* also exhibits a clustered distribution on the host.

Typically, observed hair damage and loss associated with moderate to severe pediculosis is most apparent along the dorsal midline of the body especially between the shoulder blades (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). The clinical signs of pediculosis tend to be more noticeable between the shoulder blades due to more mechanical breakage of the long guard hairs of the mane from a scratching response to the pruritis. However, within cattle lice, hair length was not significantly correlated with lice abundance (Watson *et al.,* 1997). Our study shows that the lowest mean proportion of lice is found within the neck region and the higher mean proportions within the groin and rump.

Currently, it is unknown why the groin and rump region of the wolf is favored by *T. canis*, whereas the neck area possesses the lowest proportion of active life stages of lice. The pelage of the groin is relatively thin as compared to the mane of the wolf, which possesses long erectile guard hairs (Mech, 1970). It is possible that these areas possess different microclimates and could affect the survival of *T. canis*. Ambient humidity and temperature has been shown to be important limiting factors of lice abundance (Moyer and Wagenbach, 1995; James *et al.,* 1998; Carrillo *et al.,* 2007). In addition, as the severity of hair damage increases with moderate to severe pediculosis, the total insulative properties of the wolf pelage could decrease (Scholander *et. al.* 1950; Hammel, 1955). This could potentially expose lice to detrimental climatic conditions, potentially increasing lice morbidity and mortality. Currently the range of environmental conditions favored by *T. canis*, and how the progression of clinical signs of pediculosis affects lice distribution and mortality is unknown.

Under the Convention on International Trade of Endangered Species (CITES), harvested wolves within Alaska are required to be brought to an ADF&G office or designated official for inspection and sealing. This provides biologists the opportunity to visually inspect wolf pelts for presence of *T. canis*. While mild infestations can go unnoticed, moderate to severe pediculosis can be detected by trained personnel via visual examination of the groin and rump region of the wolf, which possesses the highest proportion of *T. canis* (Table 1.1). In addition, louse-infested wolves often display symptoms of pediculosis between the shoulder blades that could aid in verifying louse presence. The groin region also presents a relatively easier location for visual detection of lice due to the reduced fur density and low presence of debris, which can reduce sightability (Watson *et al.,* 1997).

All live-capture/released wolves and coyotes should also be examined for *T. canis*. In live-captured animals, a lice index or count can be used to estimate *T. canis* loads and pediculosis severity from standardized sites (Milnes *et al.,* 2003). We recommend that the location of this sampling site be the groin and rump region. Actual counts of a small standardized site can provide more accurate description of pediculosis, and allow for more precise comparisons of infestation over time.

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Literature Cited

CARRILLO, M. C., F. VALERA, A. BARBOSA, AND E. MORENO. 2007. Thriving in an arid environment: High prevalence of avian lice in low humidity conditions. Ecoscience 14: 241-249.

CLAYTON, D. H., AND D. M. DROWN. 2001. Critical Evaluation of five methods for quantifying chewing lice (*Insecta: Phthiraptera)*. Journal of Parasitology 86: 1291-1300.

DURDEN, L. A. 2001. Lice (*Phthiraptera*). *In* Parasitic Diseases of Wild Mammals, W. M. Samuel, M. J. Pybus, and A. A. Kocan (eds.). 2nd Edition. Iowa State University Press, Ames, Iowa, pp. 3-17.

GARDNER, C., AND K. BECKMEN. 2007. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1 July 2006-June 2007. Federal Aid in Wildlife Restoration. Grant W-33-5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

HAMMEL, H. T. 1955. Thermal Properties of fur. American Journal of Physiology 182: 369-376.

HARPER, P. (ed.). 2006. Wolf management report of survey and inventory activities. 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA.

JAMES, P. J., R. D. MOON, AND D. R. BROWN. 1998. Seasonal dynamics and variation among sheep in densities of sheep biting louse, *Bovicola ovis*. International Journal for Parasitology 28: 283-292.

MASTELLER, M. 2000. Unit 14 wolf management report. *In* Wolf management report of survey-inventory activities, M. Hicks (ed.). 1 July 1996-30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 88-112.

MECH, D. L. 1970. The wolf itself. *In* The Wolf: The Ecology and Behaviors of an Endangered Species, D. L. Mech (ed.). University of Minnesota Press, pp. 1-37.

MILNES, A. S., C. J. O'CALLAGHAN, AND L. E. GREEN. 2003. A longitudinal study of a natural lice infestation in growing cattle over two winter periods. Veterinary Parasitiology 116: 67-83.

MOYER, B. R., AND G. E. WAGENBACH. 1995. Sunning by Black Noddies (*Anous minutus*) May Kill Chewing Lice (*Quadraceps hopkinsi*). The Auk 112: 1073-1077.

SALL, J., AND A. LEHMAN. 1996. JMP Start Statistics: A guide to statistics and data analysis using JMP and JMP IN software. SAS Institute Inc Duxbury press, Belmont, California.

SCHOLANDER, P. F., V. WALTERS, R. HOCK, and L. IRVING. 1950. Body insulation of some arctic and tropical mammals and birds. Biological Bulletin 99: 225-236.

SCHWARTZ, C. C., R. STEPHENSON, AND N. WILSON. 1983. *Trichodectes canis* on the gray wolf and coyote on Kenai Peninsula, Alaska. Journal of Wildlife Diseases 19: 372-373.

SELINGER, J. 2006. Unit 7 and 15 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002- 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 59-64.

TAYLOR, W. P., J. R., AND T. H. SPRAKER. 1983. Management of a biting louse infestation in a free-ranging wolf population. *In* Annual Proceedings: American Association of Zoo Veterinarians, M. E. Fowler (ed.). American Association of Zoo Veterinarians., Atlanta, Georgia, pp. 40-41.

WALL, R., AND D. SHEARER. 2001. Lice (*Phthiraptera*). *In* Veterinary ectoparasites: biology, pathology, and control, 2nd Edition, Blackwell Science, London, pp.162-178.

WATSON, D. W., J. E. LLOYD, AND E. KUMAR. 1997. Density and distribution of cattle lice (Phthiraptera: Haematopinidae, Linognathidae, Trichodectidae) on six steers. Veterinary Parasitology 69: 283-296.

WELCH, D.A., AND W. M. SAMUEL. 1989. Evaluation of random sampling for estimating density of winter ticks (*Dermacentor albipictus*). International Journal for Parasitology 19: 691-694.

ZARNKE, R. L. 1985. Experimental investigations of *Trichodectes canis* louse infestation in wolves. Alaska Department of Fish and Game, Federal Aid in

Wildlife Restoration. Grants W-22-3 and W-22-4, Research Final Report, Juneau, Alaska, USA.

Figure Legends

Figure 1.1: Divisions of wolf hide for lice proportion analysis utilizing potassium hydroxide digestion.

Figure 1.2: Divisions of wolf hide into 100 cm^2 subsections for lice density analysis utilizing potassium hydroxide digestion.

Table 1.1. Mean proportion of active *T. canis* life stages on Alaska gray wolves. Means with different superscripts are significantly different.

Large hide sections			100 cm^2 hide sections		
Section	Mean	SE	Section	Mean	SE
1	0.41^{a}	0.039	Back	0.65^{a}	0.059
2	0.46^{a}	0.039	Groin	0.50^{ab}	0.059
3	0.50^{a}	0.039	Neck	0.37^{ab}	0.059
4	0.64^{b}	0.039	Shoulder	0.45^{b}	0.059

Table 1.2. Detection probability of *T. canis* for Alaska wolf hide samples; including one-eighth hide sections and 100 cm^2 samples based on *T. canis* infested wolves.

Large hide sections				100 cm^2 hide sections			
Section	N	*T. canis* not detected	Detection probability	Section	N	*T. canis* not detected	Detection probability
1	21	1	0.95	Back	15	3	0.80
2	21	1	0.95	Groin	15	2	0.87
3	21	0	1.00	Neck	15	2	0.87
4	21	0	1.00	Shoulder	15	2	0.87

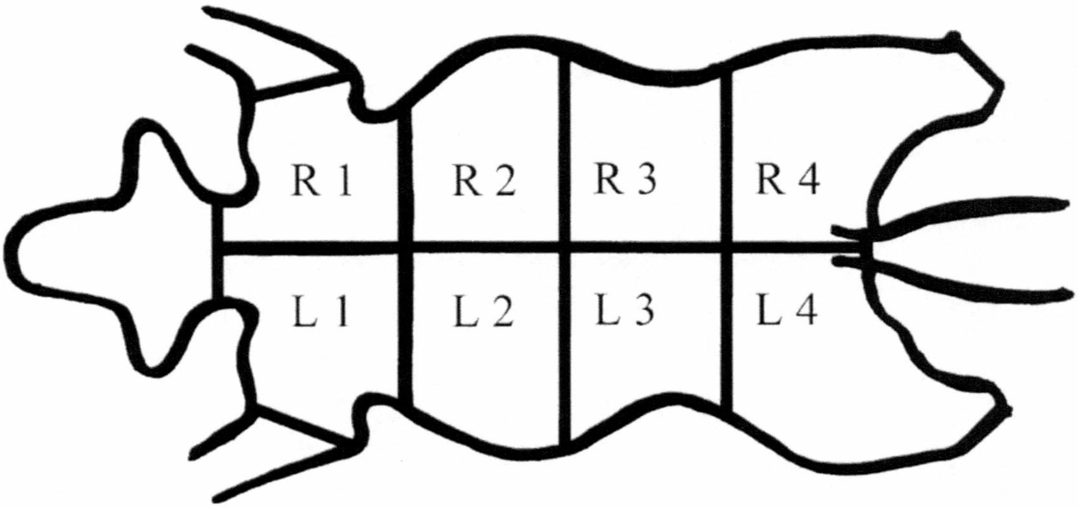

Figure 1.1. Divisions of wolf hide for lice proportion analysis utilizing potassium hydroxide digestion. Wolf hides were subdivided into four relatively equal sections and numbered from the cranial to caudal.

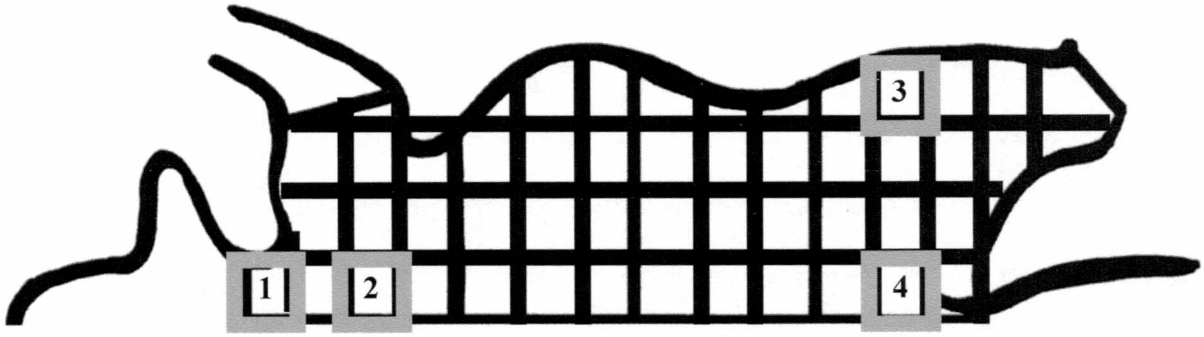

Figure 1.2. Divisions of wolf hide into 100 cm^2 subsections for lice density analysis utilizing potassium hydroxide digestion. Each hide section square represents 10 cm by 10 cm, (1 neck, 2 shoulder, 3 groin, 4 back).

Chapter 2- Distribution of *Trichodectes canis* within Alaska: an invasive ectoparasite of gray wolves?[1]

Abstract: In 1981, *Trichodectes canis* (Ischnocera: Trichodectidae), an obligate ectoparasite of canids, was first documented in Alaska on wolves (*Canis lupus*) from the Kenai Peninsula. The infestation was detected because wolves exhibited moderate to severe alopecia. In 1998, *T. canis* was identified north of the Kenai Peninsula in the Matanuska-Susitna River Valleys, north of the Alaska Range near Fairbanks in 2004, and the Upper Kuskokwim River in 2005. Two hypotheses may explain why *T. canis* was not observed in Alaska wolves until the 1980s. Symptomatic wolves could be predisposed to pediculosis, whereas mild infestations outside the observed infestation region are undetected by visual inspection. A second possible explanation is that *T. canis* is an invasive ectoparasite. In that case, Alaska wolves are unable to mount an effective response to this novel parasite, whereas wolves outside the infestation region in Alaska do not harbor *T. canis*. We examined wolf hides outside of the known distribution of the louse from December 2003 to February 2009, to determine the current distribution of *T. canis* on wolves within Alaska; thereby testing the hypothesis that *T. canis* occurs naturally as a parasite of Alaska wolves. Lice were documented on wolves in a contiguous distribution from Southcentral Alaska to immediately north of the Alaska Range, (estimated area 174,000 km^2). Wolves outside of the infestation zone do not

[1] Theresa M. Woldstad, Kimberlee B. Beckmen, Craig L. Gardner, and Kris J. Hundertmark. "Distribution of *Trichodectes canis* within Alaska: an invasive ectoparasite of gray wolves?" Prepared for submission to *Journal of Wildlife Diseases*.

possess occult infestations of *T. canis*. This pattern of occurrence suggests that *T. canis* is a novel parasite within Alaska.

Introduction

Trichodectes canis, (Ischnocera: Trichodectidae) the common biting dog louse, is an obligate ectoparasite of canids, including the gray wolf (*Canis lupus*) (Tompkins and Clayton, 1999; Durden, 2001). Transmission typically occurs from direct physical contact between hosts, and use of denning or bedding sites (Durden, 2001). Macroparasites, such as lice, typically exhibit aggregate distribution across their host populations (Wilson *et al.,* 2001). This heterogeneous distribution is caused by multiple factors, such as variation in susceptibility and exposure of individual hosts (Wilson *et al.,* 2001). Genetic diversity within the major histocompatibility complex (MHC) of the host has been found to be an important factor determining susceptibility to infestation of certain parasites (Coltman *et al.,* 1999; Owen *et al.,* 2008).

The geographical distribution and occurrence of *T. canis* within wild canids of the world is poorly documented. In general, *T. canis* is not considered a significant parasite in terms of active management of wild mammals. In the Old World, *T. canis* has been documented within the Czech Republic in raccoon dogs (*Nyctereutes procyonoides*) (Bádr *et al.,* 2005), and domestic dogs in the Faroe Islands (Palma and Jensen, 2005), Northern Spain (Domínguez, 2004), and South Korea (Chee *et al.,* 2008). Within South America, *T. canis* has been documented as a new ectoparasite of endangered Darwin foxes (*Lycalopex fulvipes*) in southern Chile (González-Acuña *et al.,* 2007), and in domestic dogs within

Brazil (Bellato *et al.,* 2003), Uruguay (Venzal *et al.,* 2006), and Panama (Emerson, 1966).

Within the contiguous United States, *T. canis* has been documented upon wolves of Minnesota, Wisconsin (Mech *et al.,* 1985), and Idaho (Nadeau *et al.,* 2007). In addition, *T. canis* is also found on coyotes (*Canis latrans*) of Washington (Golden *et al.,* 1999), Oregon (Emerson *et al.,* 1984), New York (Gompper *et al.,* 2003), Florida (Foster *et al.,* 2003), Texas (Eads, 1948), and Michigan (Mech *et al.,* 1985). Within Canada, *T. canis* has been documented on coyotes and wolves of British Columbia (Hopkins, 1960) and wolves of Ontario (Judd, 1954), and the Manitoba-Saskatchewan border (Mech *et al.,* 1985). It is important to note that this is not an exhaustive list of distribution, as *T. canis* possesses a cosmopolitan distribution within domestic dogs (Durden, 2001).

Trichodectes canis was first identified within Alaska in 1981 on wolves of the northern Kenai Peninsula (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). It was suggested that the original source population of *T. canis* within the Kenai Peninsula was domestic dogs (Schwartz *et al.,* 1983). Within the following years, numerous wolves on the Kenai Peninsula were observed with visually apparent infestations. In March, 1983, the Alaska Department of Fish and Game (ADF&G) attempted eradication management by treating pediculosis with the anitparasitic drug ivermectin (22,23-dihydroavermectin B_{1a} + 22,23-dihydroavermectin B_{1b}) by means of impregnated baits and intramuscular injections (Taylor and Spraker, 1983; Zarnke, 1985). Treatment appeared to be at least temporarily effective. However, the program was unable to eliminate the infestation from treated packs because wolves continued to exhibit moderate to severe hair loss (Selinger, 2006).

In the winter of 1992, a statewide survey was conducted to determine the extent of pediculosis in wolves and coyotes. Harvested wolves brought to ADF&G offices for official sealing were inspected visually for clinical signs and presence of *T. canis*. No evidence of pediculosis was found outside of the Kenai Peninsula (Golden *et al.,* 1999). However, in November and December of 1998, trappers reported the presence of infested wolves and coyotes 155 kilometers north of the Kenai Peninsula in the Susitna River valley (Golden *et al.,* 1999; Peltier, 2006a; Peltier, 2006b). From December 1998 to March 1999, ADF&G captured and treated 40 wolves in ten packs from the surrounding area. From inspection of the pelage, a total of 27 wolves representing three packs were infested with *T. canis* (Golden *et al.,* 1999). It is important to note that once one pack member becomes infested with *T. canis*, it is assumed that all pack members are potentially exposed through direct contact and consequently can become infested with lice.

Trichodectes canis was first detected north of the Alaska Range near Fairbanks in 2004, and the Upper Kuskokwim River in 2005 (Young, 2006; Seavoy, 2006). During summer 2006, ADF&G initiated an active management strategy utilizing ivermectin-impregnated baits south of Fairbanks. Twelve wolf packs were examined in 2006, seven of which were found to be infested with *T. canis* (Gardner and Beckmen, 2007). Prior to treatment in 2006, 58.3% of the monitored packs were louse infested; two years after *T. canis* was detected in the area (ADF&G unpublished data). During spring, infested radio-collared wolf packs were treated at ten to fourteen day intervals at den and rendezvous sites with ivermectin-impregnated baits dropped from aircraft (Gardner and Beckmen, 2007). In 2008, a total of 23 wolf packs south of Fairbanks were examined, of which only one was found infested with *T. canis* (Gardener and Beckmen, 2008). All ivermectin-treated packs were negative for *T. canis* the following fall.

The prevalence and severity of pediculosis within some regions of Alaska appears significantly higher as compared to occurrences observed within the contiguous United States. The United States Department of Agriculture conducted a control trapping of wolves within Minnesota, in which five to ten percent of the animals were found to be infested with lice (Golden *et al.,* 1999). However, roughly 68 percent of wolves infested within the Susitna River Valley and 58 percent of the packs in the Tanana River valley studies in Alaska exhibited clinical signs associated with lice infestation (Golden *et al.,* 1999; Gardner and Beckmen, 2008).

Typical clinical signs of pediculosis exhibited by wolves on the Kenai Peninsula include seborrhea as well as alopecia of both guard hairs and underfur (Schwartz *et al.,* 1983). All observed wolves infested with *T. canis* in the Kenai possessed some degree of matting or alopecia on the groin and trunk, with most hair damage being moderate (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). It is important to note that the alopecic syndrome of follicular dysplasia in Interior Alaska wolves is commonly misdiagnosed as pediculosis. Hides from wolves with follicular dysplasia were always fully dissolved and examined to confirm absence of *T. canis*. In addition to alopecia, intense pruritus, self-inflicted trauma and lesions, inflammation, and infected sores were observed (Taylor and Spraker, 1983). In general, pediculosis did not seem to affect survivorship or reproduction of the Kenai wolves, and no additive mortality was observed (Schwartz *et al.,* 1983).

Healthy individuals generally do not exhibit severe clinical signs of infestations, as small infestations of ectoparasites within wild mammals are considered normal (Durden, 2001; Roberts *et al.,* 2002). Chewing lice are not typically considered important pathogens of wild mammals as they feed on skin secretions, hair particles, and skin debris (Durden, 2001). Often, severe infestations reflect a predisposition to pediculosis, such as an immunocompromised state, malnutrition, injury, poor grooming, and age (Mech *et al.,* 1985; Wall and Shearer, 2001; Bildfell *et al.,* 2004). *Trichodectes canis* should exhibit a typical heterogeneous distribution within Kenai wolves. However, few individuals exhibit mild pediculosis and most possess visibly apparent clinical signs of infestations (Selinger, 2006).

Two hypotheses may explain why the high prevalence of pediculosis and *T. canis* infestations were not observed in Alaska wolves until the 1980s. It is possible that *T. canis* is endemic throughout Alaska and symptomatic wolves are predisposed to pediculosis either inherently or through exposure to some other agent, whereas individuals outside of the observed infestation region possess mild infestations that are not readily apparent by casual inspection (occult infestations). A second possible explanation is that *T. canis* is a recently introduced, exotic ectoparasite. In the latter case, Alaska wolves that have been exposed are seemingly unable to mount an effective response to this novel parasite, and wolves outside of the infestation region do not harbor *T. canis*. Our objectives were to determine the current distribution for *T. canis* within Alaska wolves, and test the hypothesis that *T. canis* occurs naturally in Alaska and is present in low densities in areas not characterized by symptomatic wolves.

Materials and Methods

Wolf hides and whole carcasses were procured by ADF&G, US Fish and Wildlife Service (USF&WS), and purchased from Alaska hunters and were inspected by qualified observers for *T. canis*. The majority of acquired hides were collected opportunistically by region. Whole carcasses and pelts were photographed and gross descriptions of hair loss patterns and skin lesions were recorded. Specimens of *T. canis* were collected from raw wolf hides and carcasses and were stored in 100% ethanol as vouchers and archived at the University of Alaska Museum of the North under catalog number UAM 100019480. Raw hides were stored frozen until processed.

To definitively detect *T. canis* at low parasite densities, potassium hydroxide (KOH) hide digestion was utilized (Watson *et al.,* 1997; Clayton and Drown, 2001). After a period of incubation in a KOH solution, the fur and most of the epidermis of the host is dissolved, leaving a transparent dermis and the chitinous exoskeletons of lice. Those exoskeletons can be filtered from solution and counted for determining complete parasite loads. In general, hide dissolution tends to be more precise than visual inspection or use of lice indices (Watson *et al.,* 1997; Clayton and Drown, 2001). However, this method does possess noteworthy disadvantages as louse specimens may be destroyed. Despite these drawbacks, KOH hide digestion can provide accurate estimation of pediculosis severity and detection of occult infections (Watson *et al.,* 1997; Clayton and Drown, 2001).

Lice detection from KOH digested wolf hides was conducted using the method of Welch and Samuel (1989), as modified by Woldstad *et al.,* (Chapter 1). Wolves were recorded as positive if adult lice, eggs, or larval instars were observed. Samples of other, incidental ectoparasites and environmental arthropods such as orbatid mites were collected and identified by Dr. Nixon Wilson, professor emeritus, University of Northern Iowa.

Two to three hide sections or several 10 x 10 cm subsample pieces were used to identify infested individuals if gross visual inspection did not detect lice (Woldstad *et al.,* Chapter 1). Individual wolves that exhibited low to no lice on the first tested hide section were subjected to complete hide digestion of both right and left sides. Wolves were only recorded as negative after all hide sections were digested and examined and no adult lice, instars or eggs were detected.

For areas in which whole carcasses or wolf pelts were not available, we examined Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) sealing records, obtained records of visual examination of pelts as well as anecdotal information for the presence of *T. canis* through discussions with area biologists, and reviewed ADF&G wolf management reports for documentation (Golden *et al.,* 1999). Wolves harvested within Alaska are required to be sealed under CITES, and are brought to regional ADF&G offices for sealing, where biologists inspect pelts. In general, KOH hide digestion is a more precise indicator of pediculosis than gross observation, as mild infestations can go unnoticed (Watson *et al.,* 1997; Clayton and Drown, 2001). However, moderate to severe pediculosis can be detected by visualizing lice in the thinly haired groin area and by a specific pattern of hair damage and loss along the dorsal surface of the pelt.

Likelihood of *T. canis* detection within Alaska and areas outside of the observed infestation area was calculated based on prevalence estimates from the Tanana Flats in 2006. A total of 12 wolf packs were visually inspected by ADF&G biologists, of which a total of seven packs possessed visually apparent pediculosis (Gardner and Beckmen, 2007). We assumed that the efficacy of the KOH hide digestion method was 100 percent. The probability of detection (D) of *T. canis* within a sample of wolves (N) is based upon a binomial distribution $D = 1 - (1 - p)^N$ (Gu and Novak, 2004). Utilizing the Tanana Flats prevalence (p) of 58.33%, the probability of *T. canis* detection within Alaska and outside of known infestation area was calculated. For a conservative estimation of probability of detection, we also utilized a prevalence rate of 30%.

Results

From December 2003 to February 2009, a total of 133 wolf pelts were obtained from licensed trappers, ADF&G personnel, and federal biologists, and were examined utilizing KOH hide digestion. We visually examined an additional 92 wolves. Hides examined in this study were received from Southeast Alaska, Southwest, Southcentral, Interior, Western Alaska, and the Arctic (Table 2.1, Figure 2.1).

Within the known *T. canis* infestation region of Interior and Southcentral Alaska, 92 and 11 wolves were examined using KOH hide digestion. All the wolves from Southcentral Alaska came from the Kenai Peninsula and Matanuska-Susitna River Valleys and all were infested with *T. canis* (Table 2.1, Figure 2.1). Within the known *T. canis* infestation region of Interior Alaska, wolves were examined from the Upper Kuskokwim, Tanana and Chena River drainages, Yukon-Charley Rivers National Wildlife Preserve, and Denali National Park (Figure 2.1). Of the 92 wolves examined, 29 were positive for *T. canis* (Table 2.1). It is important to note that during the course of our study, ADF&G conducted a study of experimental lice mitigation strategy utilizing repeated remotely delivered ivermectin-impregnated baits in selected packs known to be infected with lice south of Fairbanks in the Tanana River drainage (Gardner and Beckmen, 2007). Of the thirty-five wolves from the mitigation study area found negative for *T. canis* in the current study, only ten were from seven untreated packs. A total of seven wolves were collected outside of the known infestation area of Interior Alaska, three from Koyukuk River Drainages, one from Tetlin Junction, one from Galena, and two near Stevens Villages. All of which were negative for *T. canis* (Table 2.1).

Partial hides of two wolves from Southeastern Alaska with hair loss were available for examination and both were found negative for *T. canis* (Figure 2.1). Fifteen wolves from Southwestern Alaska were sampled, all of which tested negative for lice (Figure 2.1). All but two of the samples examined from Southwest Alaska were incomplete hides, consisting of a four-inch wide strip along the dorsal midline. Six wolves were collected and examined representing Western Alaska, one from Gweek and five from Nakolik Creeks, all of which were found negative for *T. canis* (Figure 2.1). It is important to note that all the Nakolik Creek wolves were obtained from one pack. Two wolves were collected from different packs within the Arctic Slope and found negative for *T. canis* (Figure 2.1; Table 2.1).

Wolf hides from several major regions within the range of the Alaska gray wolf were not available during the course of this study. Areas with no samples examined using the KOH hide digestion method include Prince of Wales Island, Copper River Delta, Prince William Sound, Wrangell-St. Elias National Park, Wood-Tikchik River drainages along Bristol Bay, eastern and western Brooks Range, Arctic National Wildlife Refuge, and the

Seward Peninsula (Figure 2.1). Within these regions, visual examination of pelts and personal communication with regional ADF&G biologists, and CITES sealing certificates were examined.

From Southcentral Alaska, 29 CITES sealing records from 1981-1982 and nine from 2004-2006 were examined. In addition, published records and management reports were also examined. Seventy-five wolves were noted to be infested within Southcentral Alaska, 25 from Eastern Upper Cook Inlet, 38 from Western Cook Inlet, two wolves from the Upper Susitna and Nelchina Rivers, and twelve from the Kenai Peninsula (Table 2.1), (Schwartz *et al.,* 1983; Golden *et al.,* 1999). *Trichodectes canis* continues to be observed on numerous Kenai Peninsula wolves; however, exact prevalence estimates are currently unavailable (Selinger, 2006).

Within the Copper River Delta, two radio-collared wolves were inspected and did not exhibit clinical signs of pediculosis. None of the wolves visually examined by ADF&G within the Copper River Delta exhibited clinical signs of pediculosis, and trappers have not reported observing infested wolves within that area. Within Wrangell–St. Elias National Park, ADF&G area biologists suggest that *T. canis* could be present due to the proximity to adjacent infested areas (Kelleyhouse, 2006). However based on trapping records, none of the wolves from this area have been found infested by *T. canis*.

Within Southeastern Alaska, wolves from Prince of Wales Island and Yakutat area have not been tested for *T. canis*. Currently, wolves have not been reported with clinical signs of pediculosis within those areas based on management reports (Porter, 2006; Barten, 2006). However, local veterinarians have diagnosed *T. canis* infestations in pet and feral dogs on Prince of Wales Island. Within the Seward Peninsula and adjacent Norton Sound drainages, *T. canis* has not been documented by regional ADF&G biologists (Persons, 2006).

Within Southwestern Alaska, wolves from the Northern Bristol Bay and Wood-Tikchik Rivers have not been examined using KOH hide digestion. The majority of wolves harvested within this area reportedly exhibit good pelt condition. However in 2006, two wolves exhibiting hair damage patterns consistent with pediculosis were trapped along the Iowithla River northeast of Dillingham. In both cases, only visual observations were made by area trappers. Without microscopic examination or visual inspection by trained personnel of these wolves, it is unknown if hair damage was the result of pediculosis or another condition, such as follicular dysplasia. Since 2006, no wolves exhibiting signs of pediculosis have been reported by area trappers.

Thirty-two wolves from areas outside of the present infestation area within Alaska were inspected for *T. canis* using KOH hide digestion. The detection probability of lice outside of the current infestation areas utilizing the observed prevalence rate of Tanana Flats is >99% (Table 2.1). Utilizing a more conservative approach, detection probability of *T.*

canis was estimated utilizing a prevalence rate of 30%. The detection probability of lice outside of the current infestation zone did not significantly change utilizing the lower prevalence rate (>99%), (Table 2.1; Table 2.2). Detection probability of *T. canis* within Southeastern Alaska and the Arctic Slope did noticeably decline to 51.0%; and Western Alaska detection probability declined to 88.2%. However, detection probabilities within Southwestern and Interior Alaska outside of the infestation zone did not decline below 99%. Currently, *T. canis* is assumed to be absent from Southwestern, Western, Southeastern and Northern Alaska. It is highly likely that *T. canis* was not present outside the known infestation area.

Discussion

We were able to assess the current distribution and prevalence of *T. canis* within Alaska by using KOH hide digestion, verbal reports from ADF&G biologists, and CITES reports. We documented *T. canis* distribution within the Kenai Peninsula, Matanuska-Susitna Valleys, Upper Kuskokwim River, Denali National Park, Yukon-Charley Rivers National Wildlife Preserve, and the Tanana River drainages south of Fairbanks (Figure 2.1). With a detection probability of >99% in most areas, it is highly unlikely that *T. canis* was present outside the known infestation area, at least in the areas we sampled (Table 2.1). Utilizing conservative prevalence estimates, the detection probability of *T. canis* outside of the current infestation zone was still greater then 99% (Table 2.2). This study strongly suggests that *T. canis* is an invasive parasite of Alaska wolves and the observed hair loss syndrome is due to the novel nature of *T. canis* in Alaska. Therefore, we reject the hypothesis that wolves outside of the infestation region possess mild infestations of *T. canis*.

Prevalence and severity of the *T. canis* infestation within certain regions within the range of Alaska wolves appears greater as compared to observations within the contiguous United States. Prevalence of *T. canis* on both wolves and coyotes within the Kenai Peninsula and the Matanuska-Susitna Valleys has increased since its original documentation (Selinger, 2006; Peltier, 2006b). From 1998 to 2008, the majority of wolves submitted for sealing from the Kenai Peninsula have exhibited gross signs of pediculosis (Selinger, 2006). In addition, all 11 wolves from Southcentral Alaska examined using KOH hide digestion were found to be infested with *T. canis* (Figure 2.1). However, the samples were not random and only wolves that have such severe hair damage as to be of no economic value were donated by trappers.

Through continuous adaptation of both *T. canis* and wolves, the majority of wolves should exhibit low to moderate pediculosis. However, in Southcentral Alaska wolves exhibit high prevalence and severity of infestation as compared to wolves within the contiguous United States. The prevalence and severity of pediculosis within Kenai Peninsula and Matanuska Susitna Valley wolves is notably higher as compared to observations of Minnesota wolves, in which 5-10% of animals were visibly infested with lice (Golden *et al.,* 1999). While the frequency of severe pediculosis within the Kenai

Peninsula and Matanuska-Susitna Valleys wolves is considered high, infested wolves north of the Alaska Range generally do not noticeably exhibit clinical signs of severe pediculosis such as seborrhea, malodor and secondary bacterial and yeast infections of the skin.

We conclude that *Trichodectes canis* infestation within Alaska wolves does not exhibit the characteristic heterogeneous distribution observed in most infested hosts of macroparasites (Wilson *et al.,* 2001). Often severe infestations reflect a predisposition to pediculosis, such as injury, malnutrition, and immunocompromised state (Mech *et al.,* 1985; Wall and Shearer, 2001). Based on the rejection of our null hypothesis, we also conclude that wolves exhibiting obvious clinical signs of pediculosis within the known infestation area are not predisposed to pediculosis more so than wolves outside of the observed infestation region. Additional evidence for this assumption was provided by the 1998 translocation of 18 wolves from eastern Interior Alaska to the Kenai Peninsula (Boertje and Gardner, 1999). Prior to transport, wolves were visually inspected by ADF&G experts Ted Spraker and Randall Zarnke and found to be free of signs of *T. canis* infections. During the winter of 1999/2000, several of the translocated wolves were harvested on the Kenai Peninsula and *T. canis* was detected upon visual examination. It is interesting to note that three of the translocated wolves dispersed from the Kenai Peninsula to Southcentral Alaska possibly contributing to the spread of *T. canis* north of the Kenai Peninsula (Boertje and Gardner, 1999).

It is unknown why Alaska wolves did not harbor *T. canis* until recently. We propose two hypotheses to explain why *T. canis* was absent from Alaska wolves. The first hypothesis is that *T. canis* was once present within Alaska wolves but with the advance and retreat of the North American ice sheets during the last Ice Age, Alaska wolves became separated from conspecifics on the remainder of the continent. Alaska wolves may have lost *T. canis* due to environmental factors, such as temperature, and over time lost resistance to louse infestation (Moyer and Wagenbach, 1995; James *et al.,* 1998; Moyer *et al.,* 2002). Alaska wolves remained isolated from *T. canis*, until the chance introduction from infested domestic dogs in 1981 on the Kenai Peninsula (Schwartz *et al.,* 1983; Taylor and Spraker, 1983; Peltier, 2006a).

The second hypothesis is that during the most recent colonization of New World by wolves, *T. canis* was not present within the colonizers. The genetically unique Northern North American wolf ecomorph vanished in the late Pleistocene megafaunal extinction (Leonard *et al.,* 2007). Modern Alaska wolves are either descendants of a secondary invasion from the Old World, or recolonization of gray wolves that took refuge below the Wisconsin ice sheet (Nowak, 1995; Leonard *et al.,* 2007). Thus, the North American wolf was free of *T. canis* until its introduction from the Old World by means of domestic dogs. Within recent years, *T. canis* has been described as a new ectoparasite of Darwin's foxes within southern Chile (González-Acuña *et al.,* 2007) and the potential origin of the infestation is believed to be domestic dogs. *Trichodectes canis* has been documented within the domestic dog populations of Brazil (Bellato *et al.,* 2003), Uruguay (Venzal *et* *al.,* 2006), and Panama (Emerson, 1966). In addition to South America, *T. canis* has also been described as a new ectoparasite of Idaho and Montana wolves (Nadeau *et al.,* 2007; Sime *et al.,* 2008). The Idaho case involved an infested individual that had attacked domestic dogs (Nadeau *et al.,* 2007). The wolf exhibited visually apparent clinical signs of pedicolosis such as alopecia.

One potential reason why wolves, at least in Southcentral Alaska, may be more prone to pediculosis is the loss of major histocompatibility complex (MHC) diversity. Diversity of MHC is thought to be maintained by a combination of inbreeding avoidance mechanisms as well as pathogen-driven selection (Kennedy *et al.,* 2007). It is possible that in the absence of *T. canis*, alleles contributing to ectoparasite resistance were lost over time. Alaska wolves do appear to lack some variation of MHC DLA alleles and haplotypes, which are found within the Northwest Territories and Yukon wolves of Canada (Kennedy *et al.,* 2007). Wolf populations within Southcentral and Southeastern Alaska show significantly lower diversity of MHC DLA alleles than typically expected (Kennedy *et al.,* 2007).

It is important to note that modern Alaska wolves are relatively recent colonizers of North America from the Beringian Refugium 10,000 years ago (Nowak, 1995; Nowak, 2003; Weckworth *et al.,* 2005). On a continental scale, the North American gray wolf exhibits a pattern of isolation with distance which has been suggested as related to climate and habitat biased dispersal (Geffen *et al.,* 2004; Carmichael *et al.,* 2007). It is likely that through geological history, physical barriers and regions of unsuitable habitat contributed to genetic differentiation between isolated wolf populations such as Alaska and Northeastern gray wolves (Nowak, 2003; Geffen *et al.,* 2004; Carmichael *et al.,* 2007). These genetic differences have likely persisted due to reduction in gene flow even after the withdraw of glacial ice sheets. Alaska wolves also exhibit genetic differentiation within Coastal and Continental populations of the Pacific Northwest (Weckworth *et al.,* 2005). It is suggested that wolves of Southeast Alaska are distinct from wolves of British Columbia, Kenai Peninsula, and Interior Alaska due to barriers to gene flow (Weckworth *et al.,* 2005; Carmichael *et al.,* 2007). Currently, it is unknown if Alaska wolves are more susceptible to *T. canis* as compared to infested wolves of Minnesota; where prevalence based on visual examination is estimated at five to ten percent (Golden *et al.,* 1999).

Additional research is required to determine potential causes of susceptibility of Alaska wolves to *T. canis*. It is possible that lower MHC diversity and historical absence of lice resulted in increased susceptibility to *T. canis* (Kennedy *et al.,* 2007). Genetic research is recommended to determine if there are differences between and within Alaska wolf populations and wolves in areas where *T. canis* is present but without severe alopecia (Leonard *et al.,* 2005; Kennedy *et al.,* 2007). In addition, continued monitoring of *T. canis* distribution within Alaska is important to adaptive management strategies, as well as investigating potential factors which influence the distribution and spread of *T. canis*.

Currently, the original source population of *T. canis* is believed to be domestic dogs of the Kenai Peninsula (Schwartz *et al.,* 1983; Peltier, 2006a). However, it is uncertain how *T. canis* spread north of the Kenai Peninsula and the Alaska Range. While domestic dogs have been proposed as potential source populations for *T. canis*; it is likely that dispersal of infested wolves resulted in the lice outbreak south of Fairbanks, due to remoteness of the infested packs first identified (Gardner and Beckmen, 2007). Wolf dispersal and emigration is common within Alaskan wolf packs, yet actual dispersal rates are difficult to estimate. It is estimated that roughly 47% of 11 month pups present within the central Brooks Range near the Gates of the Arctic National Park and Preserve would emigrate prior to reaching 36 months of age (Adams *et al.,* 2008). Dispersal distances of central Brooks Range wolves ranged from 85 to 700km from natal home ranges. Emigrating wolves of Southcentral Alaska also possessed a similar dispersal distance range of 23 to 732km (Ballard *et al.,* 1987). In addition, cases of pediculosis in Alaska domestic dogs are typically the dog sucking louse (*Linognathus setosus*) and not *T. canis* (Taylor and Spraker, 1983). It is unknown if or when *T. canis* will spread beyond its current range, or what geographical, climatic or biological factors limit the range or impede the spread of lice. It is recommended that genetic research into the Alaska lice populations be conducted to determine founding populations of *T. canis*.

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Literature Cited

ADAMS, L., G., R. O. STEPHENSON, B. W. DALE, R. T. AHGOOK, AND D. J. DEMMA. 2008. Population dynamics and harvest characteristics of wolves in the central Brooks Range, Alaska. Wildlife Monographs 170: 1-25.

BÁDR, V., P. STEFAN, AND J. PREISLER. 2005. *Trichodectes canis* (De Geer, 1778) (Phthiraptera, Ischnocera), a new ectoparasite of the raccoon dog (*Nyctereutes procyonoides*) in the Czech Republic. European Journal of Wildlife Research 51: 133-135.

BALLARD, W. B., J. S. WHITMAN, AND C. L. GARDNER. 1987. Ecology of an Exploited Wolf Population in South-Central Alaska. Wildlife Monographs 98: 3-54.

BARTEN, N. L. 2006. Unit 5. Wolf management report. *In* Wolf management report of survey and inventory activities P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 45-51.

BELLATO, V., A. A. SARTOR, A. P. SOUZA, AND B. C. RAMOS. 2003. Ectoparasites in dogs from Lages municipality, Santa Catarina, Brazil. Colégio Brasileiro de Parasitologia Veterinária 12: 95-98.

BILDFELL, R. J., J. W. MERTINS, J. A. MORTENSON, AND D. F. COTTAM. 2004. Hairloss syndrome in black-tailed deer of the Pacific Northwest. Journal of Wildlife Disease 40: 670–681.

BOERTJE, R. D., AND C. L. GARDNER. 1999. Reducing Mortality on the Fortymile Caribou Herd. Alaska Department of Fish and Game. Federal aid in wildlife restoration reserch performance report. July 1998-June 1999. Grant W-27-2, study 3.43. Juneau, Alaska, USA.

CARMICHAEL, L. E., J. KRIZAN, J . A . NAGY, E. FUGLEI, M. DUMOND, D. JOHNSON, A. VEITCH, D. BERTEAUX, AND C. STROBECK. 2007. Historical and ecological determinants of genetic structure in arctic canids. Molecular Ecology 16: 3466-3483.

CHEE, J-H., J-K. KWON, H-S. CHO, K-O. CHO, Y-J. LEE, A. M. EL-ATY, AND S-S. SHIN. 2008. A survey of ectoparasite infestation in stray dogs of Gwang-ju City, Republic of Korea. Korean Journal of Parasitology 46: 23-7.

CLAYTON, D. H., AND D. M. DROWN. 2001. Critical Evaluation of five methods for quantifying chewing lice (*Insecta: Phthiraptera)*. Journal of Parasitology 86: 1291-1300.

COLTMAN, D. W., J. G. PILKINGTON, J. A. SMITH, AND J. M. PEMBERTON. 1999. Parasite-mediated selection against inbred soay sheep in a free-living, island population. Evolution 53: 1259-1267.

DOMÍNGUEZ, G., 2004. North Spain (Burgos) wild mammals ectoparasites. Parasite 11: 267-272.

DURDEN, L. A. 2001. Lice (*Phthiraptera*). *In* Parasitic Diseases of Wild Mammals, W. M. Samuel, M. J. Pybus, and A. A. Kocan (eds.). 2nd Edition. Iowa State University Press, Ames, Iowa, pp. 3-17.

EADS, R. B. 1948. Mallophaga of the mammals Ectoparasites from a series of Texas coyotes. Journal of Mammalogy 29: 268-71.

EMERSON, K. C. 1966. Mallophaga of the mammals of Panama. *In* Ectoparasites of Panama, L. Wenzel and J. Tipton (eds.). Field Museum of Natural History, Chicago, Illinois, pp. 267-272.

__________, C. MASER, J. O. WHITAKER. 1984. Lice (Mallophaga and Anoplura) from Mammals of Oregon. Northwest Science 58: 153-161.

FOSTER, G. W., M. B. MAIN, J. M. KINSELLA, L. M. DIXON, S. P. TERRELL, AND D. J. FORRESTER. 2003. Parasitic Helminths and Arthropods of Coyotes (*Canis latrans*) from Florida, U.S.A. Comparative Parasitology 70: 162-166.

GARDNER, C., AND K. BECKMEN. 2007. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1 July 2006-June 2007. Federal Aid in Wildlife Restoration. Grant W-33-5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

__________, AND __________. 2008. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1 July 2007-June 2008. Federal Aid in Wildlife Restoration. Grant W-33-5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

GEFFEN, E., M. J. ANDERSON, AND R. K. WAYNE. 2004. Climate and habitat barriers to dispersal in the highly mobile grey wolf. Molecular Ecology 13: 2481-2490.

GOLDEN, H. N., T. H. SPRAKER, H. J. GRIESE, R. L. ZARNKE, M. A. MASTELLER, D. E. SPALINGER, AND B. M. BARTLEY. 1999. Briefing Paper on Infestation of Lice Among Wild Canids in Alaska. *In* Wolf management report of survey-inventory activities, M. Hicks (ed.). 1 July 1996-30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 98-112.

GONZÁLEZ-ACUÑA, D., C. BRICEÑO, A. CICCHINO, S. M. FUNK, AND J. JIMÉNEZ. 2007. First records of *Trichodectes canis* (Insecta: Phthiraptera: Trichodectidae) from Darwin's fox, *Pseudalopex fulvipes* (Mammalia: Carnivora: Canidae). European Journal of Wildlife Research 53: 76-79.

GOMPPER, M. E., R. M. GOODMAN, R. W. KAYS, J. C. RAY, C. V. FIORELLO, AND S. E. WADE. 2003. A Survey of the Parasites of Coyotes (*Canis latrans*) in New York based on Fecal Analysis. Journal of Wildlife Diseases 39: 712-717.

GU, W., AND R. J. NOVAK. 2004. Short report: detection probability of arbovirus infection in mosquito populations. American Journal of Tropical Medicine and Hygiene 71: 636-638.

HOPKINS, G. H. E. 1960. Notes on some Mallophaga from mammals. Bulletin of the British Museum (Natural History), Entomology 10: 75-95.

JAMES, P. J., R. D. MOON, AND D. R. BROWN. 1998. Seasonal dynamics and variation among sheep in densities of sheep biting louse, *Bovicola ovis*. International Journal for Parasitology 28: 283-292.

JUDD, W. 1954. Some Records of Ectoparasitic Acarina and Insecta from Mammals in Ontario. The Journal of Parasitology 40: 483-484.

KELLEYHOUSE, R. A. 2006. Unit 13 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 90-99.

KENNEDY, L. J., J. M. ANGLES, A. BARNES, L. E. CARMICHAEL, A. D. RADFORD, W. E. R. OLLIER, AND G. M. HAPP. 2007. DLA-DRB1, DQA1, and DQB1 Alleles and Haplotypes in North American Gray Wolves. Journal of Heredity 98: 491-499.

LEONARD, J. A.., C. VILÁ, K. FOX-DOBBS, P. L. KOCH, R. K. WAYNE, AND B. VAN VALKENBURGH. 2007. Megafaunal Extinctions and the Disappearance of a Specialized Wolf Ecomorph. Current Biology 17: 1146-1150.

__________, C. VILÁ, AND R. K. WAYNE. 2005. Legacy lost: genetic variability and population size of extirpated US grey wolves (*Canis lupus*). Molecular Ecology 14: 9-17.

MECH, L. D, R. P. THIEL, S. H. FRITTS, AND W. E. BERG. 1985. Presence and effects of the dog louse *Trichodectes canis* (Mallophaga, Trichodectidae) on wolves and coyotes from Minnesota and Wisconsin. American Midland Naturalist 114: 404-405.

MOYER, B. R., D. M. DROWN, AND D. H. CLAYTON. 2002. Low humidity reduces ectoparasite pressure: Implications for host life history evolution. Oikos 97: 223-228.

__________, AND W. G., WAGENBACH. 1995. Sunning by Black Noddies (*Anous minutus*) May Kill Chewing Lice (*Quadraceps hopkinsi*). The Auk 112: 1073-1077.

NADEAU, M. S., C. MACK, J. HOLYAN, J. HUSSEMAN, M. LUCID, P. FRAME, AND B. THOMAS. 2007. Wolf conservation and management in Idaho, progress report 2006. Idaho Department of Fish and Game and Nez Perce Tribe. Boise, Idaho, USA.

NOWAK, R. W. 1995. Another look at wolf taxonomy. *In* Ecology and conservation of wolves in a changing world, L. N. Carbyn, S. H. Fritts, and D. R. Seip (eds.). Canadian Circumpolar Institute, Edmonton, Alberta, Canada, pp. 375-397.

__________, 2003. Wolf Evolution and Taxonomy. *In* Wolves: Behavior, Ecology, and Conservation, D. L. Mech, and L. Boitani (eds.). University of Chicago Press, Chicago, Illinois, USA, pp. 239-258.

OWEN, J. P., M. E. DELANY, AND B. A. MULLENS. 2008. MHC haplotype involvement in avian resistance to an ectoparasite. Immunogenetics 60: 621-631.

PALMA, R. L., AND J-K. JENSEN. 2005. Lice (Insecta: Phthiraptera) and their host associations in the Faroe Islands. Steenstrupia 29: 49-73

PELTIER, T. 2006a. Unit 14 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 100-108.

__________, 2006b. Unit 16 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 109-117.

PERSONS, K. 2006. Unit 22 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 210-217.

PORTER, B. 2006. Unit 2 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 29-37.

ROBERTS, M. G., A. P. DOBSON, P. ARNEBERG, G. A. DE LEO, R. C. KRECEK, M. T. MANFREDI, P. LANFRANCHI, AND E. ZAFFARONI. 2002. Parasite community ecology and biodiversity. *In* The Ecology of Wildlife Diseases, P. J. Hudson, A. Rizzoli, B. T. Grenfell, H. Heesterbeek, and A. P. Dobson (eds.). Oxford University Press, pp. 63-82.

SCHWARTZ, C. C., R. STEPHENSON, AND N. WILSON. 1983. *Trichodectes canis* on the gray wolf and coyote on Kenai Peninsula, Alaska. Journal of Wildlife Diseases 19: 372-373.

SEAVOY, R. J. 2006. Unit 19 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005.

Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 136-153.

SELINGER, J. 2006. Unit 7 and 15 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (ed.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 59-64.

SIME, C. A., V. ASHER, L. BRADLEY, K. LAUDON, M. ROSS, J. TRAPP, M. ATKINSON, AND J. STEUBER. 2008. Montana gray wolf conservation and management 2007 annual report. Montana Fish, Wildlife and Parks. Helena, Montana, pp. 137.

TAYLOR, W. P., JR., AND T. H. SPRAKER. 1983. Management of a biting louse infestation in a free-ranging wolf population. *In* Proceedings: Annual Proceedings of the American Association of Zoo Veterinarians, M. E. Fowler (ed.). Tampa, Florida, pp. 40-41.

TOMPKINS, D. M. AND D. H. CLAYTON. 1999. Host resources govern the specificity of swiftlet lice: Size matters. Journal of Animal Ecology 68: 489-500.

WALL, R., AND D. SHEARER. 2001. Lice (*Phthiraptera*). *In* Veterinary ectoparasites: biology, pathology, and control, 2nd Edition, Blackwell Science, London, pp.162-178.

WATSON, D. W., J. E. LLOYD, AND E. KUMAR. 1997. Density and distribution of cattle lice (Phthiraptera: Haematopinidae, Linognathidae, Trichodectidae) on six steers. Veterinary Parasitology 69: 283-296.

WECKWORTH, B. V., S. TALBOT, G. K. SAGE, D. K. PERSON, AND J. COOK. 2005. A Signal for Independent Coastal and Continental histories among North American wolves. Molecular Ecology 14: 917-931.

WELCH, D.A., AND SAMUEL, W. M. 1989. Evaluation of random sampling for estimating density of winter ticks (*Dermacentor albipictus*). International Journal for Parasitology 19: 691-694.

WILSON K., O.N. BJØRNSTAD, A. P. DOBSON, S. MERLER, G. POGLAYEN, S. E. RANDOLPH, A. F. READ, AND A. SKORPING. 2001. Heterogeneities in macroparasite infections: Patterns and processes. *In* The ecology of wildlife diseases, P. J, Hudson A. Rizzoli, B. T. Grenfell, H. Heesterbeek, A. P. Dobson (eds.). Oxford University Press, Oxford, pp. 6-44.

VENZAL, J. M., O. CASTRO, C. DE SOUZA, AND O. CORREA. 2006. New Records of lice Trichodectidae (Phthiraptera: Ischnocera) for Uruguay. Veterinaria Montevideo 41: 31-34.

YOUNG, D. D. 2006. Unit 20A, 20B, 20C, 20F and 25C wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002-30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 154-165.

ZARNKE, R. L. 1985. Experimental investigations of *Trichodectes canis* louse infestation in wolves. Alaska Department of Fish and Game, Federal Aid in Wildlife Restoration. Grants W-22-3 and W-22-4, Research Final Report. Juneau, Alaska, USA.

Figure Legends

Figure 2.1: The current distribution of *T. canis* within Alaska wolves.

Table 2.1. Probability of *T. canis* detection in Alaska based on a 58.33 percent prevalence rate.

	Method of Inspection		Result of Inspection		Probability of detection	
Locality	KOH Hide Digestion	Visual Examination	Number Negative	Number Positive	KOH Hide Digestion	Total examined wolves
Southeastern	2	2	4	0	82.6	97.0
Southwestern	15	0	15	0	>99.9	>99.9
Southcentral	11	83	0	94	>99.9	>99.9
Interior (inside infestation zone)	90	2	63	29	>99.9	>99.9
Interior (outside infestation zone)	7	0	7	0	99.8	99.8
Western	6	0	6	0	99.5	99.5
Arctic Slope	2	5	7	0	82.6	99.8
Total (inside infestation zone)	101	85	63	123	>99.9	>99.9
Total (outside infestation zone)	32	7	39	0	>99.9	>99.9
Total (Alaska)	133	92	102	123	>99.9	>99.9

Table 2.2. Probability of *T. canis* detection in Alaska based on a conservative prevalence rate of 30 percent.

	Method of Inspection		Result of Inspection		Probability of detection	
Locality	KOH Hide Digestion	Visual Examination	Number Negative	Number Positive	KOH Hide Digestion	Total examined wolves
Southeastern	2	2	4	0	51.0	76.0
Southwestern	15	0	15	0	99.5	99.5
Southcentral	11	83	0	94	98.0	>99.9
Interior (inside infestation zone)	90	2	63	29	>99.9	>99.9
Interior (outside infestation zone)	7	0	7	0	91.8	91.8
Western	6	0	6	0	88.2	88.2
Arctic Slope	2	5	7	0	51.0	91.8
Total (inside infestation zone)	101	85	63	123	>99.9	>99.9
Total (outside infestation zone)	32	7	39	0	>99.9	>99.9
Total (Alaska)	133	92	102	123	>99.9	>99.9

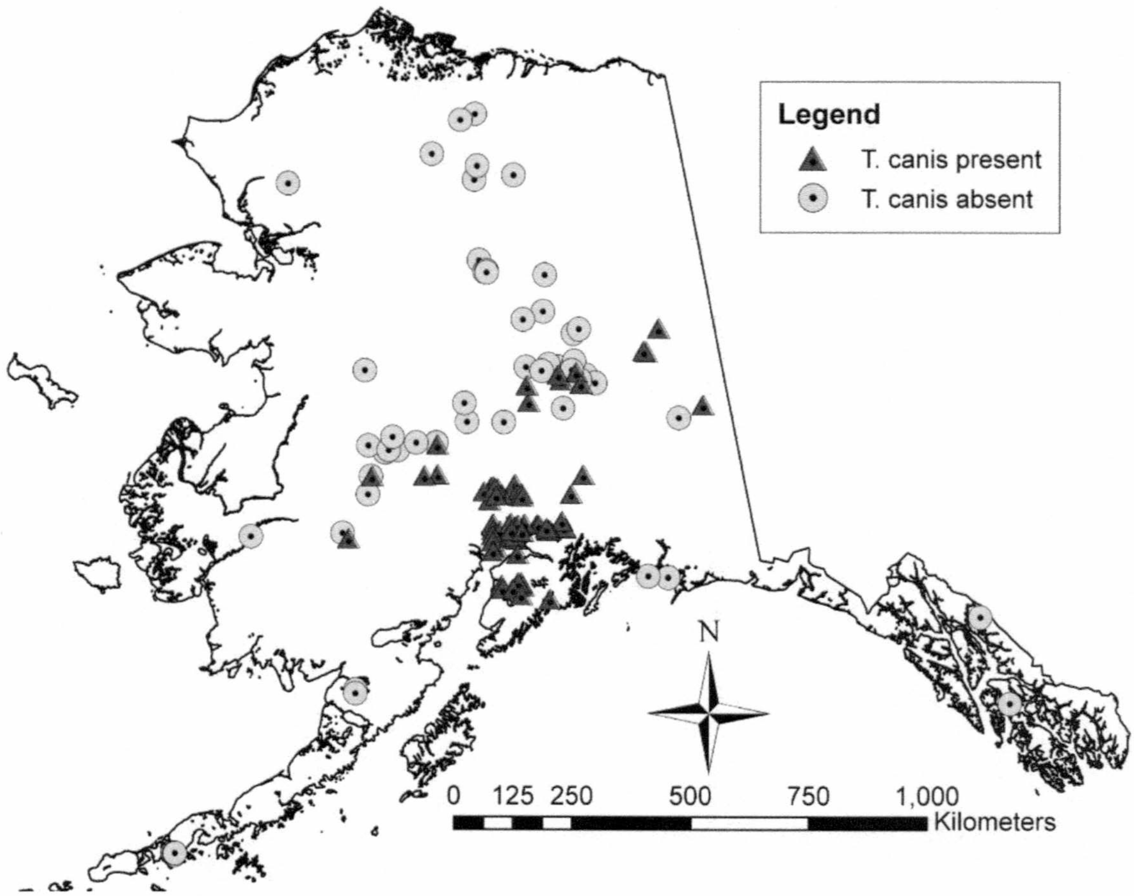

Figure 2.1. Current distribution of *T. canis* within Alaska wolves. Triangles represent wolves found infested with *T. canis*. Circles represent wolves which were found negative for *T. canis* utilizing potassium hydroxide digestion or visual examination.

Chapter 3- Ecological correlates of distribution and spread of an invasive ectoparasite of Alaska gray wolves [1]

Abstract: *Trichodectes canis*, (Ischnocera: Trichodectidae), an invasive louse infesting Alaska gray wolves (*Canis lupus*), was first documented on the Kenai Peninsula in Southcentral Alaska in 1981. In following years, numerous wolves exhibited visually apparent, moderate to severe infestations. Population expansions of *T. canis* occurred sporadically and the louse currently occupies portions of Southcentral and Interior Alaska. Ecological correlates of *T. canis* distribution and spread within Alaska wolves were examined utilizing logistic regression and model selection criteria. Realized niche models for *T. canis* were developed for current and future climatic conditions. Predictor variables positively associated with *T. canis* presence include wolf densities and mean January temperatures > -19°C. Models suggest that the current distribution of *T. canis* in Alaska is constrained by temperature and wolf densities. Predictive models of future temperature suggest that *T. canis* could expand its current range along the western coast of Alaska including the Seward Peninsula.

[1] Theresa M. Woldstad, Falk Huttmann, and Kris J. Hundertmark. "Ecological correlates of distribution and spread of an invasive ectoarasite of Alaska gray wolves." Prepared for submission to *Ecography*.

Introduction

Trichodectes canis (Ischnocera: Trichodectidae), the biting dog louse, has recently been described as an invasive parasite within Alaska wolves (Woldstad *et al.* Chapter 2). The first documented occurrence of *T. canis* in Alaska occurred in 1981 on the Kenai Peninsula (Schwartz *et al.* 1983, Taylor and Spraker 1983). Clinical signs of lice infestation include seborrhea (dandruff), alopecia (hair loss) of both guard hairs and underfur, and matting of the underfur and breakage of guard hairs typically between the shoulder blades and in the groin area (Schwartz *et al.* 1983, Taylor and Spraker 1983). A treatment program implemented by Alaska Department of Fish and Game (ADF&G) using an antiparastitc drug proved unsuccessful in eliminating the lice infestations from packs in the region (Taylor and Spraker 1983). By the early 1990s, all known wolf packs within the Kenai Peninsula exhibited clinical signs of pediculosis, and *T. canis* continues to persist throughout the Kenai Peninsula (Golden *et al.* 1999, Spraker 2000, Selinger 2006).

In the winter of 1991, two wolves within the Knik River Valley north of the Kenai Peninsula exhibited clinical signs of pediculosis (infestation of lice), (Golden *et al.* 1999). The wolves were identified as dispersers from the Kenai Peninsula. Initiating a preventative management strategy, ADF&G attempted to confine the infestation to the Kenai Peninsula by treating infested wolves with ivermectin (Golden *et al.* 1999). Treatment proved successful based on subsequent inspection of harvested wolves. However, wolves were found to be infested within the nearby lower Susitna River Valley in 1998 (Golden *et al*. 1999, Spraker 2000, Selinger 2006). The subsequent treatment program by ADF&G proved to be unsuccessful and *T. canis* spread to adjacent areas (Woldstad *et al*. Chapter 2). The current distribution of *T. canis* within Southcentral Alaska (south of the Alaska Range) includes the Matanuska-Susitna Valleys and west of the Nelchina Basin (Woldstad *et al*. Chapter 2). *Trichodectes canis* has not been observed within Prince William Sound to the east of the Kenai Peninsula (Woldstad *et al*. Chapter 2). It has been suggested that the geographical barrier of the Chugach Mountains has inhibited the spread of *T. canis* by limiting wolf dispersal (Crowley 2006, Woldstad *et al*. Chapter 2). However, the specific mechanisms limiting the spread of *T. canis* are speculative.

The first documented case of pediculosis within wolves north of the Alaska Range occurred in 2004, south of Fairbanks within the Tanana Flats (Woldstad *et al*. Chapter 2). Currently, ADF&G has successfully eliminated lice infestations in Tanana Flats packs (Gardner and Beckmen 2008, Woldstad *et al*. Chapter 2). However, *T. canis* has subsequently (2005-2008) been detected on wolves within adjacent areas east, west, and south near Delta Junction, Yukon-Charley Rivers National Preserve, and Denali National Park. In 2005, other Interior Alaska wolves further to the southwest of Fairbanks (Hoholitna, Holitna, and Kuskokwim River drainages), were found to be infested with *T. canis* (Woldstad *et al*. Chapter 2).

The distribution of *T. canis* is not ubiquitous across the state of Alaska. Currently, lice appear to be confined within parts of Southcentral and Interior Alaska. *Trichodectes* *canis* has not been documented on wolves examined from Southeastern, Western, and Northern Alaska (Figure 3.1; Woldstad *et al.* Chapter 2). However, biotic and abiotic factors that influence the distribution and spread of *T. canis* are currently unknown.

Temperature has been suggested as an important factor preventing ectoparasite establishment in Alaska, such as winter tick (*Dermacentor albipictus*; Zarnke *et al.* 1990). In addition to invasive species, temperature has also been shown to regulate population size of native parasitic insects such as spruce beetles (*Dendroctonus rufipennis*; Berg *et al.* 2006). While chewing lice (suborder Mallophaga) are obligate parasites and spend most of their life cycle within the host plumage or pelage, those lice also exhibit temperature sensitivity (Ash 1960). Variations in ambient temperature have been shown to affect lice densities (Ash 1960, Moyer and Wagenbach 1995, James *et al.* 1998). Chewing lice possess a narrow preferred range of temperature, in which maximum survival is typically found between 30°C and 40°C (Ash 1960, Moyer and Wagenbach 1995). Temperatures above 40°C can be lethal to the active life stages of lice (Moyer and Wagenbach 1995), as well as the eggs (Nelson and Murray 1971). Environmental conditions experienced during normal sunning behavior of birds have been shown to be lethal to chewing lice, most likely due to elevated body temperature (Moyer and Wagenbach 1995). Mean temperatures below 11.5°C and maximum temperatures below 15°C are associated with declines in lice populations (James *et al.* 1998). Whereas ambient temperatures have been shown as limiting factors of lice fecundity and survival, temperature is also important in determining distribution and range expansion of several insect species (Crozier 2003, Battisti *et al.* 2005). One example is the northern range expansion of the skipper *Atalopedes campestris*, which recently colonized areas exhibiting a 3ºC rise in January minimum temperature since the 1950s (Crozier 2003).

Over the last century, the state of Alaska has exhibited a 1.4˚C rise in mean annual temperatures, significant decreases in the frequencies of cold weather intervals below -40˚C, and decrease in annual mean diurnal temperatures ranges (Stafford *et al.* 2002, Wendler and Shulski 2009). In general, air temperature within Alaska is a factor of local events as well as the Pacific Decadal Oscillation (PDO) index, El Niño Southern Oscillation (ENSO), and Pacific North American Circulation (PNAC) pattern (Papineau 2001, Hartmann and Wendler 2005). The interactions among those weather patterns can influence Alaska temperature on a variety of time scales (Papineau 2001, Hartmann and Wendler 2005), and could consequentially influence the distribution and spread of *T. canis* within Alaska if temperature is a limiting factor.

In addition to climatic factors, it has been suggested that an important determinant of ectoparasite abundance and transmission is host population densities (Krasnovet *et al.* 2002, Whiteman and Parker 2004). In general, parasite abundance and transmission is thought to increase with higher densities of host species, as this could provide more available habitat (Arneberg *et al.* 1998, Krasnov *et al.* 2002, Roberts *et al.* 2002). Wolf populations are composed of territorial social units; as such, transmission of lice can be classified as either within a given pack, between adjacent packs, or contact with unrelated dispersing wolves. Spread by direct contact, *T. canis* can be transmitted within a pack though social interactions, mating, and between packs through gradual dispersal of pack members after extraterritorial movements (Fritts and Mech 1981, Ballenberghe 1983, Peterson *et al.* 1984, Durden 2001). Transmission of lice between packs and unrelated wolves can occur from intraspecific strife between packs and dispersing wolves, acceptance of new breeders, and adoption of alien wolves (Fritts and Mech 1981, Ballenberghe 1983, Peterson *et al.* 1984, Durden 2001, Mech and Boitani 2003). It is likely that intrapack transmission rates are greater due to higher rates of physical contact as compared to physical contact between neighboring wolf packs. However, chance physical contact with potentially infested dispersers can result in infection of the pack and subsequent spread within adjacent packs.

Lice transmission rates between and within Alaska wolf packs are unknown. It is likely that *T. canis* transmission rates are influenced by dispersal rates, mortality, social structure, prey availability, and wolf densities. Immigration and emigration rates of wolves are dependent on availability of open territories or breeding slots; as well as prey availability, social structure, and mortality, which dictate wolf densities (Peterson *et al.* 1984, Boyd and Pletscher 1999, Fuller *et al.* 2003). Dispersal rates of wolves across Alaska are currently not available; however, estimates of wolf densities, which are dependent on social structure, mortality rates, and prey vulnerability, are available across Alaska. While wolf densities may not completely describe the potential spread and transmission of *T. canis* within and between wolf packs, it does present an estimate of potential lice habitat.

Effective management strategies for invasive species depend upon gaining an understanding of underlying factors that influence distribution and rate of spread. Geographic Information Systems (GIS) modeling of landscape features can be an effective step towards describing existing underlying patterns of distribution, investigating potential ecological correlates, and developing prospective management strategies for invasive species. Here we examine the current distribution of *T. canis* in Alaska in relation to biotic and abiotic factors and develop relative occurrence indices for current and future conditions. We hypothesize that temperature and host densities are factors correlated with *T. canis* distribution and spread.

Methods

Presence/absence of *T. canis* was determined from examination of 204 Alaska gray wolves. Wolves were examined for *T. canis* using combinations of potassium hydroxide (KOH) hide digestion, visual inspection, histopathology, and personal communication with biologists (Woldstad *et al.* Chapter 2). Hide digestion is the most sensitive indicator of occult pediculosis (Watson *et al.* 1997, Clayton and Drown 2001), and the most frequently utilized in this study. A total of 117 wolves was examined for *T. canis* utilizing a KOH dissolution technique. Of the 117 inspected wolves, 52 were collected from packs south of Fairbanks, and 26 were from packs experimentally treated with an anti-parasitic drug. Treated wolves were from packs known to be positive for *T. canis* prior to treatment. Utilizing ArcGIS version 9.2 (Environmental Systems Research Institute (ESRI)), presence and absence of *T. canis* was mapped across Alaska.

Environmental factors potentially constraining distribution of *T. canis* (wolf densities and mean annual temperatures) were also considered in the analysis.

Wolf density estimates within Alaska were based on ADF&G wolf management reports (Hicks 2000, Healy 2003, Harper 2006), and a comprehensive effort in 2002 to estimate densities statewide (ADF&G, unpublished data), (Figure 3.2). It is important to note that wolf densities naturally vary greatly from region to region depending on prey density, mortality rates, and social structure (Fuller *et al.* 2003). In addition, wolf density estimates vary with the precision of the methods used to derive them over variable landscapes due to logistical and financial constraints. However, given the limited and sporadic nature of wolf population estimates, we utilized the only available population assessment across Alaska for one concurrent year.

Mean temperatures across Alaska for both the months of January and August from 1980 to 2008 were obtained from Scenarios Network for Alaska Planning database (SNAP, http://www.snap.uaf.edu/). We utilized the ECHAM5 model and the midrange emission scenario model A1B from SNAP for temperature estimates. For future climatic scenarios, we utilized an average of mean annual temperatures from years 2029 through 2039 for the months of January and August.

The statistical program JMP (SAS Institute Inc.) was employed for model development of *T. canis* presence and absence within Alaska. Utilizing the three predictor variables, seven models were evaluated (Table 3.1). Models were constructed utilizing the nominal logistic fit function in JMP. Relative model rank was evaluated utilizing the corrected

Akaike's information criterion (AICc) and the Bayesian information criterion (BIC). The AICc provides an estimation of the Kullback-Leibler information for the observed data distribution and the fitted model, while correcting for small sample size bias (Hurvich and Tsai 1995, Buckland *et al.* 1997). In comparison, the BIC provides a consistent estimation of the Kullback-Leibler information at various sample sizes (Buckland *et al.* 1997). Competing models were defined as models less than two AICc units removed from the best-performing model. Models considered to be reasonably plausible were defined as >2 but <4 AICc units removed from the best-performing model. The remaining models which possessed AICc values greater than four units from the best-performing model were considered poor representations of observed data.

Akaike weights were also calculated for all constructed models. Akaike weight provides a normalized relative likelihood of hypothesized models (Anderson *et al.* 2001, Johnson and Omland 2004). Models which possess Akaike weights approaching one are considered exceptionally well supported by data. From the Akaike weights, relative importance of a given predictor variable can be estimated to assess the relative contributions of a particular variable in predicting occurrence of *T. canis*. Relative importance is calculated using the sum of Akaike weights for models in which a given variable is present (Johnson and Omland 2004).

The statistical program TreeNet (Salford Systems) was also utilized for estimation of variable importance and development of relative index of occurrences. TreeNet is a data-mining algorithm that can detect meaningful interactions between numerous predictor variables and dependent variables (Craig and Huettman 2009). For each model, TreeNet describes the contributions of each predictor variable in explaining the presence or absence of *T. canis* within Alaska as an importance value. Model success is based on prediction accuracy of presence and absence, and receiver operating characteristic integral (ROC) for *T. canis* presence. In general, a ROC curve is a quantitative metric that plots the false positive rates against the true positive rates for each threshold (Fawcett 2006). Utilizing TreeNet, we developed a relative index of occurrence for *T. canis* within Alaska based on AIC competing models. It is important to note that the relative index of occurrences is not a true probability, rather it is a ratio that describes the strength of association between a given predictor variable and occurrence of lice (Keating and Cherry 2004).

Results

Of the seven hypothesized models, one was found to be a competing model (model 7) with the best-performing model (model 4) according to AICc (Table 3.2). Utilizing BIC, there were no competing or reasonably plausible models other than the best-performing model (model 4; Table 3.2). The best model identified by AICc and BIC incorporated two variables, January temperature and wolf density (model 4; Table 3.2).

Akaike weights were calculated for estimation of relative likelihood of a given model (Buckland *et al.* 1997, Anderson *et al.* 2001, Johnson and Omland 2004). Reviewing the two AICc competing models, we find that model 4 possessed a 73% probability of representing the observed data among hypothesized models. However, model 7 also possessed a relatively high Akaike weight of 27% (Table 3.2). Models 4 and 7 represent a total weight greater than 99.9%, and both included the effects of January temperature and wolf density (Table 3.2).

Relative importance of each of the four predictive variables was calculated using Akaike weights (Anderson *et al.* 2001, Johnson and Omland 2004). January temperature possessed the highest relative importance value (>99.99%), followed by wolf densities (99.91%), (Table 3.3). August temperature possessed the lowest relative importance of 26.67% (Table 3.3). Given the high relative importance of January temperature and wolf densities, it is likely that those variables represent important ecological correlates of distribution and spread of *T. canis* in Alaska wolves.

Based on logistic regression, we found a significant relationship between mean January temperature and occurrence of lice ($R^2 = 0.498$, $\chi^2 = 120.4$, df = 1). The suggested temperature threshold for *T. canis* was observed at the inflection point of -19.2°C (Figure 3.3). We also found a significant, positive correlation between presence of *T. canis* and wolf densities ($R^2 = 0.0473$, $\chi^2 = 11.4$, df = 1), with a suggested inflection point of 1.1 wolves per 1000 km^2 (Figure 3.4). Wolf densities did not possess a clear inflection point as compared to January temperature (Figure 3.3 and 3.5). A positive correlation was suggested between *T. canis* presence and mean annual August temperate, with lice presence indicated at temperatures > 5.2°C (Figure 3.4). However, the relationship between *T. canis* presence and mean annual August temperate was not significant (R^2 = 0.0133, χ^2 = 3.2, df = 1).

To further assess potential threshold estimates, we utilized TreeNet to analyze the competing and plausible models based on AICc weights (models 4 and 7). The best approximate model using TreeNet ROC integrals was model 7 (97.2), followed by model 4 (96.3; Table 3.4). However, the degree of separation between models 4 and 7 was <1. Model accuracy for *T. canis* presence for both models was 97.96%, and was 75.44% for absence (Table 3.4). This suggests that prediction of *T. canis* presence is robust for both models. Both TreeNet and AICc suggest that models 4 and 7 are highly representative of the observed data.

Partial dependence plots were created for models 4 and 7 illustrating their corresponding predictor variables. For model 4, potential threshold estimates of *T. canis* presence are suggested at mean annual January temperature warmer than -18.3°C and wolf densities greater than eight wolves per 1000 km^2 (Figure 3.6). For model 7, similar estimated potential thresholds were observed for wolf densities and January temperature. For August mean annual temperature, a threshold estimate >10°C was observed (Figure 3.7). Potential threshold estimates for wolf densities and January temperature are robust across both the competing and reasonably plausible models (Table 3.2; Figures 3.6 and 3.7).

Model 4 was considered for development of relative indices of occurrence for *T. canis* within Alaska utilizing ArcMap (Figure 3.8). The relative index of occurrence for the top AICc model indicates high occurrence within Western Alaska from the Alaska Peninsula along the western coast to the Seward Peninsula (Figure 3.8). A relative high index of occurrence is also identified within Southeastern Alaska. Within Interior Alaska, a high index of occurrence is observed 50 kilometers north of Fairbanks and 144 kilometers to the northeast within Yukon-Charley Rivers National Preserve within east central Alaska. Low relative index of occurrence is found within northern Alaska and along the mountain ranges of the Kuskokwim, Chugach and Alaska Ranges (Figure 3.8).

For prediction of occurrence under future climatic conditions using the best-performing model, high relative likelihood of *T. canis* occurrence increases north and northeast of Fairbanks within Yukon-Charley Rivers National Preserve and just south of the Yukon-Flats National Wildlife Refuge. Within Western Alaska, increased relative occurrence indices are observed within the upper Yukon River and east of Kotzebue Sound. Within Southcentral Alaska, relatively higher index of occurrence is identified within the Nelchina Basin (Figure 3.8).

Discussion

Based on the current distribution of *T. canis* we conclude that cold temperatures in January and low wolf densities may constrain its spread across Alaska. Wolf densities may work to affect spread of the parasite in the short term as densities are quite dynamic over time and space. Temperature, on the other hand, is a slow-moving but directional variable that likely will affect louse distribution over longer time scales.

Currently, *T. canis* has not been documented in Southwestern Alaska despite the occurrence of favorable conditions for spread. However, infested wolves have been documented within the North Fork of the Kuskokwim River of Interior Alaska, which flows to Southwestern Alaska (Woldstad *et al.* Chapter 2). It is possible that infested wolves will travel southwest following the lower elevation river corridors, such as the Yukon and Kuskokwim Rivers. Wolves reside throughout Southwest Alaska, with the highest densities in the major river drainages of Nushagak and Mulchatna Rivers (Woolington 2006). Depending on the occurrence of open territories or breeding slots, once introduced, it is possible that *T. canis* will rapidly spread within Southwestern Alaska.

Historical population dynamics of Alaska wolves do appear correlated with *T. canis* distribution in Alaska since its first introduction in 1981 (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). The estimated fall wolf population within the area surrounding Upper Cook Inlet, north of the Kenai Peninsula, was low during the mid to late 1980s. However, during the early 1990s, wolf population increased within eastern Upper Cook Inlet, mostly due to high prey densities (Masteller 2000a, Peltier 2006a). Specifically, increased winter moose mortality during the winter of 1989 to 1990 was associated with a marked increase in wolf population. In the subsequent year, *T. canis* was first documented north of the Kenai Peninsula within that area (Golden *et al.* 1999, Peltier 2006a). The wolf population within eastern Upper Cook Inlet remained high and increased to a peak of 120 to 150 animals in the winter of 1998 to 1999 when *T. canis* was found in the lower

Susitna River Valley of Upper Cook Inlet in 1998 (Golden *et al.* 1999, Spraker 2000, Peltier 2006a). Within western Cook Inlet, the wolf population was also increasing from the early 1990s to 120-140 wolves in fall 1998, roughly twice the 1994 fall estimate of 57-79 wolves (Masteller 2000b). Wolf populations continued to increase, and peaked in the winter of 2001 to 2002 with a fall estimate of 160-245 wolves (Peltier 2006b). As wolf densities increase, a larger number of pups are produced, which in turn increases competition for available prey (Fuller *et al.* 2003, Mech and Boitani 2003). As food competition increases and pups mature, the potential for pack budding and splitting, as well as dispersing, increases (Mech and Boitani 2003). It is possible that regions that exhibit high intrinsic rates of population growth are more susceptible to successful immigration of infested wolves. Once these high-density areas are infested, they could serve as potential reservoirs for *T. canis* as infested wolves disperse to regions with vacant territories.

Whereas increasing wolf populations were observed in Southcentral Alaska during potential range expansion events; the wolf populations of the Northern Kuskokwim River were reduced from 650-970 wolves in 2002-2003 to 404-478 wolves in 2005-2006 (Seavoy 2006). In 2005, while the wolf population was declining, *T. canis* was first documented in the North Fork of the Kuskokwim River (Woldstad *et al.* Chapter 2). It is possible that the availability of vacant territories, potential for high wolf densities, and proximity to relatively high-density infestation zones of the Tanana Flats and Cook Inlet could have contributed to the establishment of infested immigrating wolves (Peterson *et* *al*. 1984, Mech and Boitani 2003), (Figure 3.2). It is also important to note that as wolf harvest increases, the average pack size decreases and proportion of pups within the population increases (Peterson *et al*. 1984). Areas that possess high harvests and the potential for high intrinsic rate of population growth could be more susceptible to *T. canis* infestation as compared to regions with limited territory vacancies and low density potential. Currently, it is unknown how wolf population dynamics can contribute or inhibit the spread of *T. canis* within Alaska.

Distribution and rate of spread for invasive parasites such as *T. canis* are influenced by host densities and dispersal, as well as biotic and abiotic factors that affect parasite survival and fecundity. Temperature thresholds for several species of lice have been observed, including *Bovicola ovis*; in which a marked population decline was observed when daily mean temperatures were 11.5°C and maximum daily mean temperatures were below 15°C (James *et al*. 1998). Our results also indicate a temperature threshold between -19.2°C to -18.3°C for *T. canis* on free-ranging wolves in Alaska (Figure 3.3 and 3.6). This is suggestive that *T. canis* is subject to climatic factors that could limit its range as compared to its potential hosts.

Over the last century Alaska has experienced state-wide increases in mean annual temperatures (Stafford *et al*. 2002, Wendler and Shulski 2009). Interactions between local weather events and periodic climatic conditions can influence Alaska temperature on a variety of time scales (Papineau 2001, Hartmann and Wendler 2005), and could consequently influence *T. canis* distribution and spread if temperature is a limiting factor. Currently, the northern limit of *T. canis* within North America is not well defined. To the south of the known latitude where lice exist in Alaska, *T. canis* has been documented in British Columbia (Hopkins 1960), the Manitoba-Saskatchewan border (Mech *et al.* 1985), and Ontario (Judd 1954). However, it is unknown if *T. canis* is present within Nunavut, Northwest Territories, or the Yukon Territory. Currently, the Yukon-Charley Rivers National Preserve is the northernmost documented case of *T. canis* within North America wolves (Woldstad *et al.* Chapter 2).

Whether the observed climatic thresholds are due to environmental factors affecting *T. canis* fecundity and survival or are an artifact of how this invasive parasite is expanding its range is unclear, as the relative occurrence models only extrapolate based on the current distribution of *T. canis* within Alaska. It is possible that the observed correlation with lice presence could be the result of recent host dispersal patterns and spread of an invasive ectoparasite. Continued research and monitoring of lice is required to improve present estimates of *T. canis* relative occurrence index, as estimates of habitat thresholds are based on *T. canis* current distribution. Currently, the fundamental niche for *T. canis* is undefined. We recommend that field and laboratory research be conducted to determine potential climatic constraints.

The long term effects of pediculosis for Alaska wolf populations are currently unknown. Under moderate and severe pediculosis, matting of the pelage from sebaceous secretions and alopecia can result in increased thermoregulation costs. On the population scale, fecundity and survival can be adversely affected. The infestation of *T. canis* on Alaska wolves could also have significant economic impact in terms of the extrinsic value of wolves as a furbearer; pelt value of moderate to severely infested animals are significantly reduced. This could potentially impact the mixed subsistence-cash economies of rural Alaska. In addition, wolves also provide important economic benefits in associated tourism (Fritts *et al.* 2003). *Trichodectes canis* can reduce wildlife viewing quality, as infested wolves may exhibit signs of pediculosis such as frequent scratching and rubbing as well as overall poor condition (Schwartz *et al.* 1983, Taylor and Spraker 1983). It is unknown how *T. canis* could impact associated tourism within infested national parks and wilderness areas of Alaska such as Denali National Park. Additional research is required to assess potential effects of *T. canis* on Alaska wolf populations and to evaluate prospective management strategies and impacts.

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Literature Cited

Anderson, D. R. et al. 2001. Suggestions for presenting the results of data analyses. – J. Wildl. Manage. 65: 373–378.

Arneberg, P. et al. 1998. Host densities as determinants of abundance in parasite communities. – Proc. R. Soc. Lond. B Biol. Sci. 265: 1283–1289.

Ash, J. S. 1960. A study of the Mallophaga of birds with particular reference to their ecology. – Ibis 102: 93–110.

Ballenberghe, V. V. 1983. Extraterritorial Movements and Dispersal of Wolves in Southcentral Alaska. – J. Mammal. 64: 168–171.

Battisti, A. et al. 2005. Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. – Ecol. Appl. 15: 2084–2096.

Berg, E. E. et al. 2006. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. – For. Ecol. Manage. 227: 219–232.

Boyd, D. K. and Pletscher, D. H. 1999. Characteristics of Dispersal in a Colonizing Wolf Population in the Central Rocky Mountains. – J. Wildl. Manage. 63: 1094–1108.

Buckland, S. T. et al. 1997. Model Selection: An integral part of inference. – Biometrics 53: 603–618.

Clayton, D. H. and Drown, D. M. 2001. Critical Evaluation of five methods for quantifying chewing lice (Insecta: Phthiraptera). – J. Parasitol. 86: 1291–1300.

Craig, E. and Huettman, F. 2009. Using “black box” algorithms such as TreeNet and Random Forests for data–mining and for finding meaningful patterns, relationships, and outliers in complex ecological data: An overview, an example using golden eagle satellite data and an outlook for a promising future. – In: Hsiao–Fan, W. (eds), Intelligent Data Analysis: Developing new methodologies through pattern discovery and recovery. Information Science Reference, pp. 65–84.

Crowley, D. W. 2006. Unit 6 wolf management report. – In: Harper, P. (eds), Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 52–58.

Crozier, L. 2003. Winter warming facilitates range expansion: cold tolerance of the butterfly *Atalopedes campestris*. – Oecologia 135: 648–656.

Durden, L. A. 2001. Lice (Phthiraptera). – In: Samuel W. M. et al. (eds), Parasitic Diseases of Wild Mammals. Iowa State Univ. Press, pp. 3–17.

Fawcett, T. 2006. An introduction to ROC analysis. – Pattern Recognit. Lett. 27: 861–874.

Fritts, S. H. and Mech, L. D. 1981. Dynamics, Movements, and Feeding Ecology of a Newly Protected Wolf Population in Northwestern Minnesota. – Wildl. Monogr. 80: 3–79.

Fritts, S. H. et al. 2003. Wolves and humans. – In: Mech, L. D. and Boitani, L. (eds), Wolves: behavior, ecology, and conservation. University of Chicago Press, pp. 289–316.

Fuller, T. K. et al. 2003. Wolf population dynamics. – In: Mech, L. D. and Boitani, L. (eds), Wolves: behavior, ecology, and conservation. University of Chicago Press, pp. 161–191.

Gardner, C. and Beckmen, K. 2008. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1 July 2006–June 2007. Federal Aid in Wildlife Restoration. Grant W–33–5. Project 14.25. – Alaska Department of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

Golden, H. N. et al. 1999. Briefing Paper on Infestation of Lice Among Wild Canids in Alaska. – In: Hicks, M. (ed). Wolf management report of survey–inventory activities. 1 July 1996-30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 98–112.

Harper, P. (ed). 2006. Alaska Department of Fish and Game. Wolf management report of survey–inventory activities. 1 July 2002–30 June 2005. – Juneau, Alaska, USA.

Hartmann, B. and Wendler, G. 2005. The significance of the 1976 Pacific climate shift on the climatology of Alaska. – J. Clim. 18: 4824–4839.

Healy, C. (ed). 2003. Alaska Department of Fish and Game. Wolf management report of survey–inventory activities. 1 July 1999–30 June 2002. – Juneau, Alaska, USA.

Hicks, M. (ed). 2000. Alaska Department of Fish and Game. Wolf management report of survey–inventory activities. 1 July 1996–30 June 1999. – Juneau, Alaska, USA.

Hopkins, G. H. E. 1960. Notes on some Mallophaga from mammals. – Bull. Br. Mus. (Nat. Hist.) Entomol.10: 75–95.

Hurvich, C. M. and Tsai, C. 1995. Model Selection for Extended Quasi–Likelihood Models in Small Samples. – Biometrics 51: 1077–1084.

James, P. J. et al. 1998. Seasonal dynamics and variation among sheep in densities of sheep biting louse, *Bovicola ovis*. – Int. J. Parasitol. 28: 283–292.

Johnson, B. J. and Omland, K. S. 2004. Model selection in ecology and evolution. – Trends Ecol. Evol. 19: 101–108.

Judd, W. 1954. Some Records of Ectoparasitic Acarina and Insecta from Mammals in Ontario. – J. Parasitol. 40: 483–484.

Keating, K. A. and Cherry, S. 2004. Use and Interpretation of Logistic Regression in Habitat-Selection Studies. – J. Wildl. Manage. 68: 774–789.

Krasnov, B. et al. 2002. The effect of host density on ectoparasite distribution: and example of a rodent parasitized by fleas. – Ecology 83: 164–175.

Masteller, M. 2000a. Unit 14 wolf management report. – In: Hicks, M. (eds). Wolf management report of survey–inventory activities. 1 July 1996 – 30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 88–112.

__________. 2000b. Unit 16. Wolf management report. – In: Hicks, M. (eds). Wolf management report of survey-inventory activities. 1 July 1996 – 30 June 1999. Alaska Department of Fish and Game. Juneau, Alaska, USA, pp. 113–122.

Mech, D. L. et al. 1985. Presence and effects of the dog louse *Trichodectes canis* (Mallophaga, Trichodectidae) on wolves and coyotes from Minnesota and Wisconsin. – Am. Midl. Nat. 114: 404–405.

__________. and Boitani, L. 2003. Wolf Social Ecology. – In: Mech, D. L. and Boitani, L. Wolves: Behavior, Ecology, and Conservation. The University of Chicago Press, pp. 1-34.

Moyer, B. R. and Wagenbach, G. E. 1995. Sunning by Black Noddies (*Anous minutus*) May Kill Chewing Lice (*Quadraceps hopkinsi*). – Auk 112: 1073–1077.

Nelson, B. C. and M. D. Murray. 1971. The distribution of Mallophaga on the domestic pigeon (*Columba livia*). – Int. J. Parasitol. 1: 21–29.

Papineau, J. M. 2001. Wintertime temperature anomalies in Alaska correlated with ENSO and PDO. – Int. J. Climatol. 21: 1577–1592.

Peltier, T. 2006a. Unit 14 wolf management report. – In: Harper P. (eds), Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 100–108.

__________. 2006b. Unit 16 wolf management report. – In: Harper P. (eds), Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 109–117.

Peterson, R. O. et al. 1984. Wolves of the Kenai Peninsula, Alaska. – Wildl. Monogr. 88: 3–52.

Roberts, M. G. et al. 2002. Parasite community ecology and biodiversity. – In: Hudson, P. J. et al. (eds), The Ecology of Wildlife Diseases. Oxford University Press, pp. 63–82.

Schwartz, C. C. et al. 1983. *Trichodectes canis* on the gray wolf and coyote on Kenai Peninsula, Alaska. – J. Wildl. Dis. 19: 372–373.

Seavoy, R. J. 2006. Unit 19 wolf management report. – In: Harper, P. (eds). Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 136–153.

Selinger, J. 2006. Unit 7 and 15 wolf management report. – In: Harper, P. (eds). Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 59–64.

Spraker, T. H. 2000. Unit 7 and 15 wolf management report. – In: Hicks, M. V. (eds). Wolf management report of survey and inventory activities. 1 July 1996 – 30 June 1999. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 50–56.

Stafford, J. M. et al. 2002. Temperature and precipitation of Alaska: 50 year trend analysis. – Theor. Appl. Climatol. 67: 33–44.

Taylor, W. P. and Spraker, T. H. 1983. Management of a biting louse infestation in a free-ranging wolf population. – Annu. Proc. Am. Assoc. Zo. Vet. 1983: 40–41.

Watson, D. W. et al. 1997. Density and distribution of cattle lice (Phthiraptera: Haematopinidae, Linognathidae, Trichodectidae) on six steers. – Vet. Parasitol. 69: 283–296.

Wendler, G. and Shulski, M. 2009. A Century of Climate Change for Fairbanks, Alaska. – Arctic 62: 295–300.

Whiteman, N. K. and Parker, P. G. 2004. Effects of host sociality on ectoparasite population biology. – J. Parasitol. 90: 939–947.

Woolington, J. D. 2006. Unit 17 wolf management report. – In: Harper, P. (eds). Wolf management report of survey and inventory activities. 1 July 2002 – 30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 118–125.

Zarnke, R. L. et al. 1990. Factors influencing the potential establishment of the winter tick (*Dermacentor albipictus*) in Alaska. – J. Wildl. Dis. 26: 412–415.

Figure Legends

Figure 3.1: *Trichodectes canis* distribution within sampled Alaskan wolves relative to annual mean January temperature.

Figure 3.2: *Trichodectes canis* distribution within sampled Alaskan wolves relative to estimated wolf densities (Wolves / 1000 km^2).

Figure 3.3: Partial dependence plots of *T. canis* presence for mean annual January temperature.

Figure 3.4: Partial dependence plots of *T. canis* presence for wolf density (Wolves / 1000 km^2).

Figure 3.5: Partial dependence plots of *T. canis* presence for mean annual August temperature.

Figure 3.6: Partial dependence plots of *T. canis* presence for the best performing model described by AICc and analysed using TreeNet.

Figure 3.7: Partial dependence plots of *T. canis* presence for the second ranked model as described by AICc and analysed using TreeNet.

Figure 3.8: Relative index of occurrence for *T. canis* within the state of Alaska based on the top competing models ranked by AICc.

Table 3.1. Hypothesized models evaluating potential ecological correlates of *T. canis* distribution in Alaska gray wolves.

Model number	Hypothesized model description	Variable abbreviation
1	January temperature	Jtemp
2	Wolf density	Wd
3	August temperature	Atemp
4	January temperature, Wolf density	Jtemp+ Wd
5	January temperature, August temperature	Jtemp+Atemp
6	Wolf density, August temperature	Wd +Atemp
7	January temperature, Wolf density, August temperature	Jtemp+ Wd +Atemp

Table 3.2. Ranking of hypothesized models evaluating potential ecological correlates of *T. canis* distribution in Alaska gray wolves. Hypothesized models were ranked by AICc.

Model Rank	Model Number	Model	K	-LN(L)	AICc	BIC	ΔAICc	W_i
1	4	Jtemp + Wd	3	51.2	108.6[A]	118.4[B]	0.0	0.73
2	7	Jtemp + Wd +Atemp	4	51.2	110.6[A]	123.6	2.0	0.27
3	1	Jtemp	2	60.6	125.4	131.9	16.8	1.7E-04
4	6	Jtemp + Atemp	3	60.2	126.5	136.3	18.0	9.2E-05
5	2	Wd	2	115.1	234.4	240.9	125.8	3.5E-28
6	5	Atemp + Wd	3	114.6	235.4	245.1	126.9	2.1E-28
7	3	Atemp	2	119.2	242.6	249.1	134.0	5.7E-30

K: Number of model parameters, including an error term. -LN(L): Negative log-likelihood of hypothesized model. W_i: AICc weight for hypothesized model.

[A] Competing models ranked by AICc. [a] Reasonably plausible models ranked by AICc.

[B] Competing models ranked by BIC. [b] Reasonably plausible models ranked by BIC.

Table 3.3. Relative importance of variables based on sum of the Akaike weights for each hypothesized variable across all included models.

Variable Rank	Hypothesized ecological correlates	Relative importance
1	January temperature	>99.99%
2	Wolf density	99.91%
3	August temperature	26.67%

Table 3.4. Model accuracy in predicting *T. canis* absence and presence, and receiver operating characteristic integral.

Model Rank	Model	Model accuracy Absence	Presence	ROC
1	Jtemp+Atemp+Density	75.44	97.96	97.2
2	Jtemp+Density	75.44	97.96	96.3

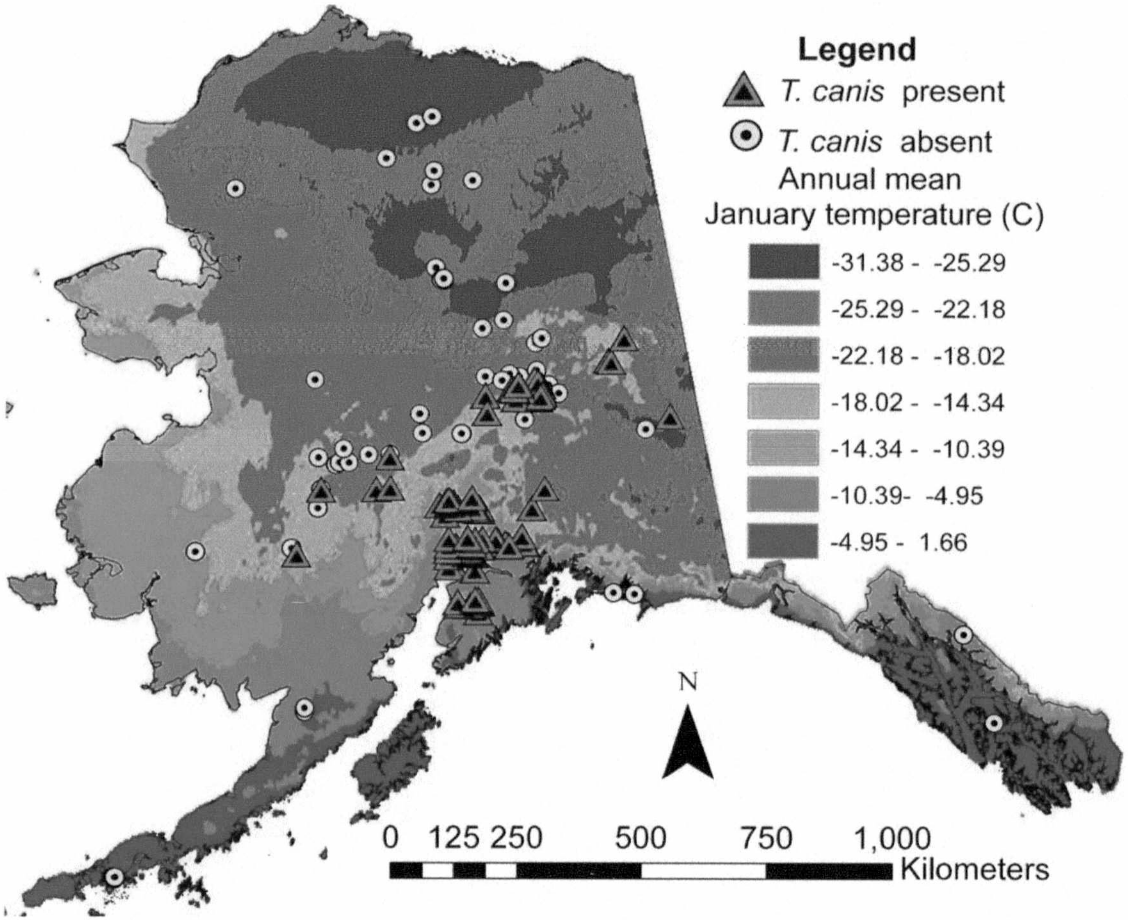


Figure 3.1. *Trichodectes canis* distribution within sampled Alaskan wolves relative to annual mean January temperature. Triangles represent wolves found infested with *T. canis* utilizing potassium hydroxide digestion or visual examination.

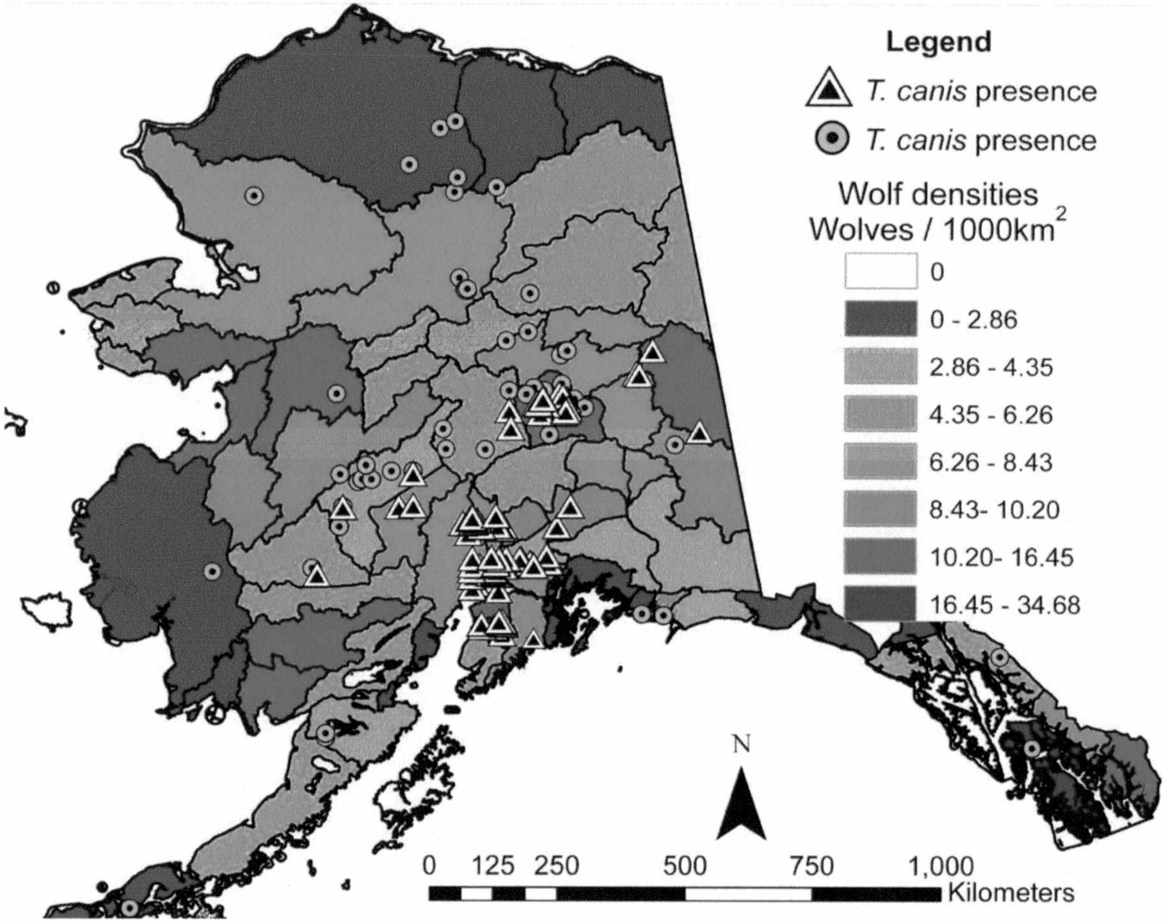


Figure 3.2. *Trichodectes canis* distribution within sampled Alaskan wolves relative to estimated wolf densities (Wolves / 1000 km^2). Triangles represent wolves found infested with *T. canis* utilizing potassium hydroxide digestion or visual examination, circles represent wolves found negative for lice.

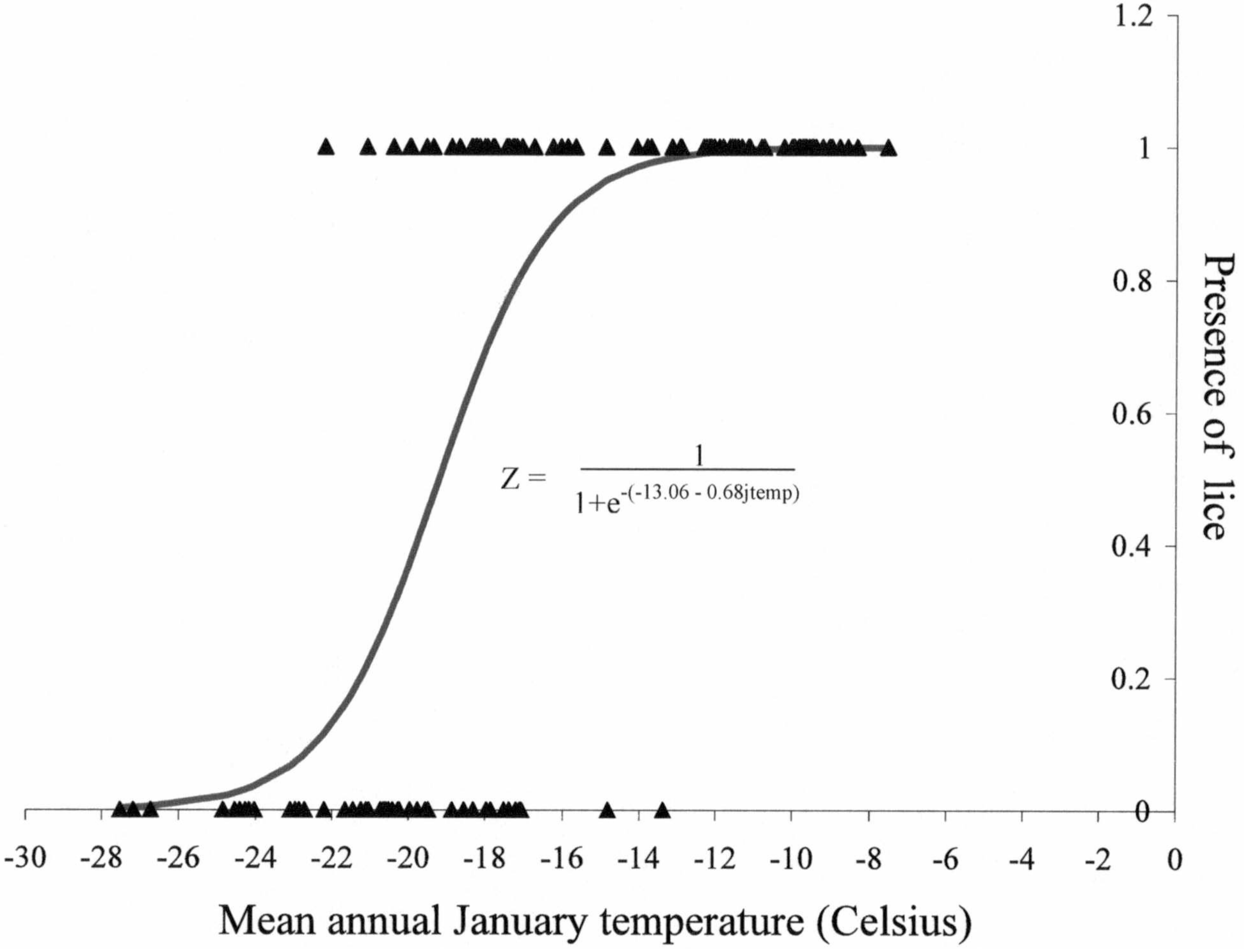


Figure 3.3. Partial dependence plots of *T. canis* presence for mean annual January temperature. Suggested habitat thresholds are indicated at line inflection point (0.50).

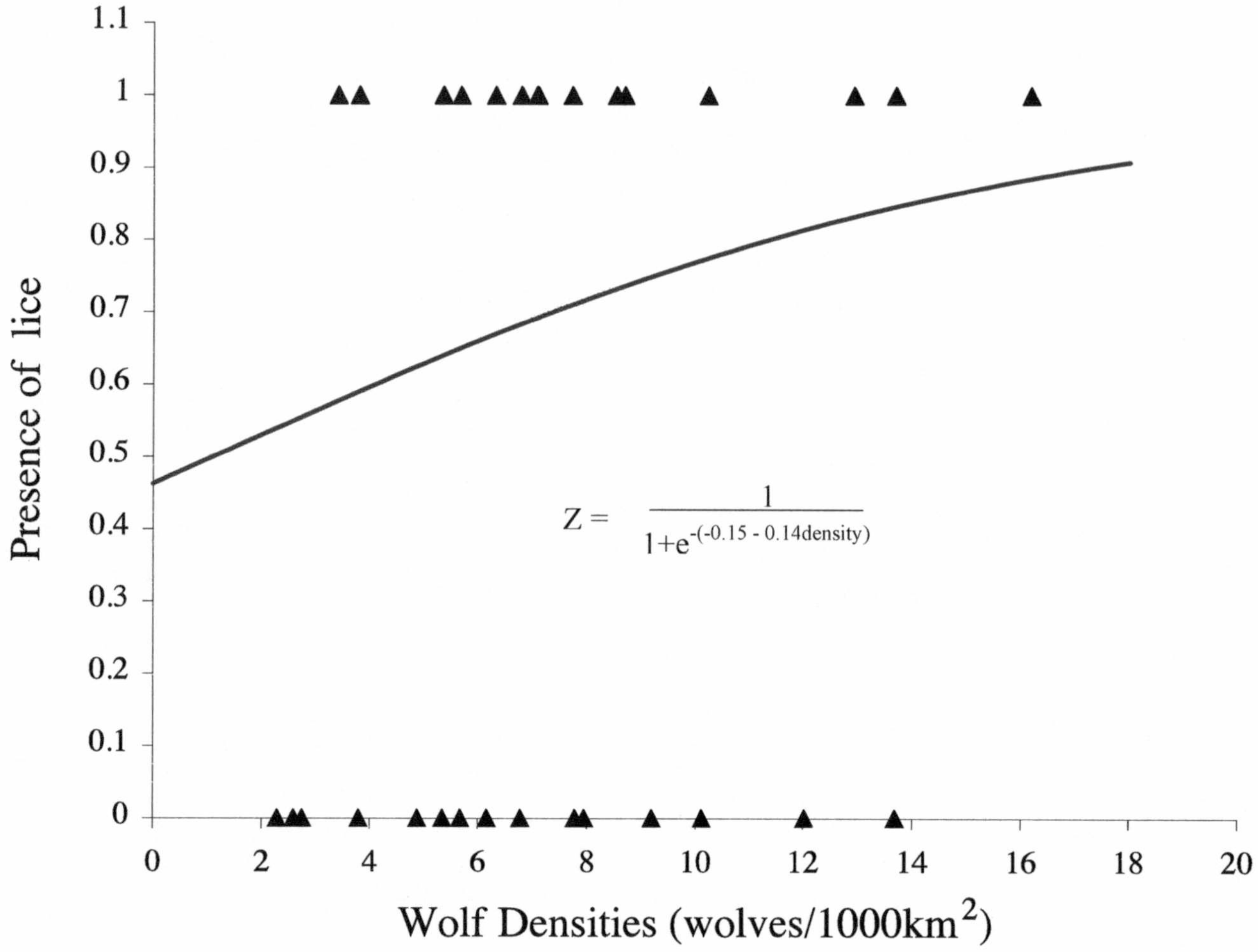


Figure 3.4. Partial dependence plots of *T. canis* presence for Alaska wolf density. Suggested habitat thresholds are indicated at line inflection point (0.50).

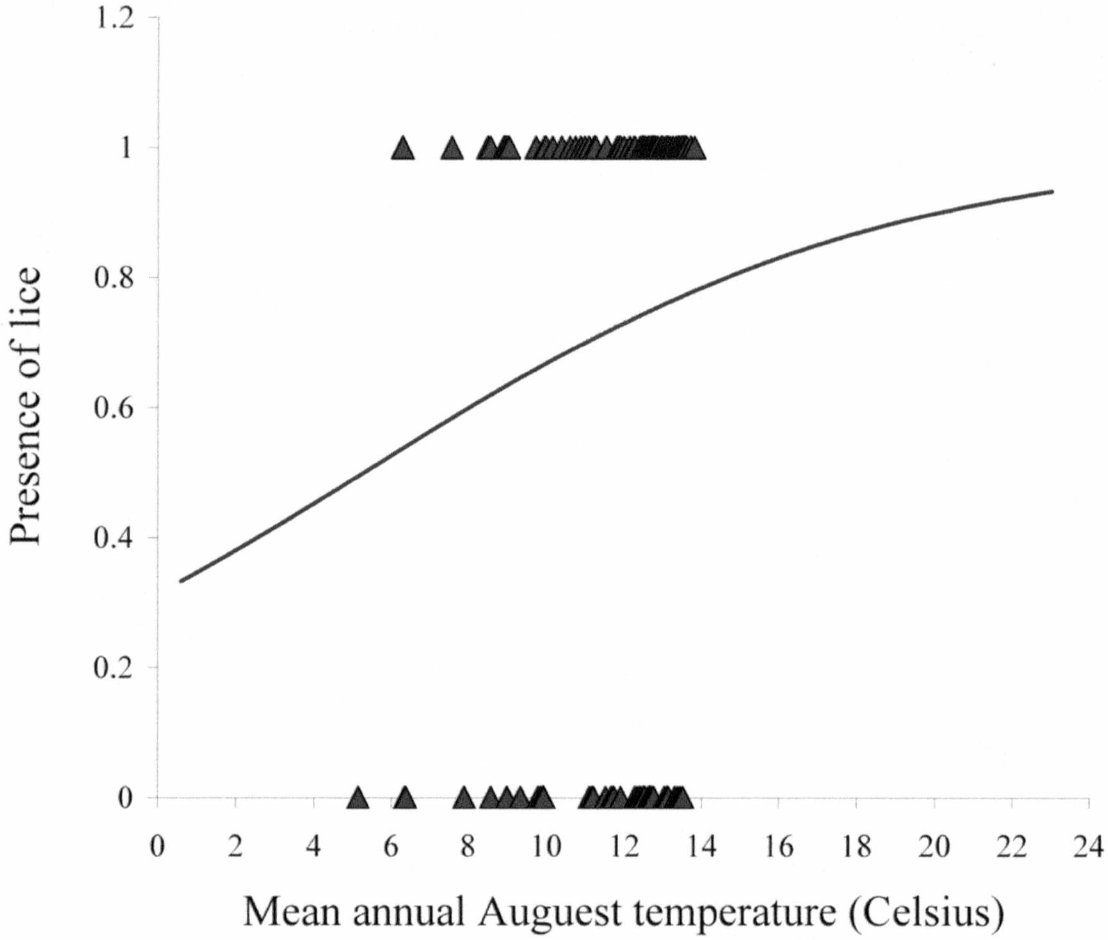


Figure 3.5. Partial dependence plots of *T. canis* presence for mean annual August temperautre. Suggested habitat thresholds are indicated at line inflection point (0.50).

A) Mean annual temperature for January (Celsius) B) Wolf density (Wolves per 1000 kilometers squared)

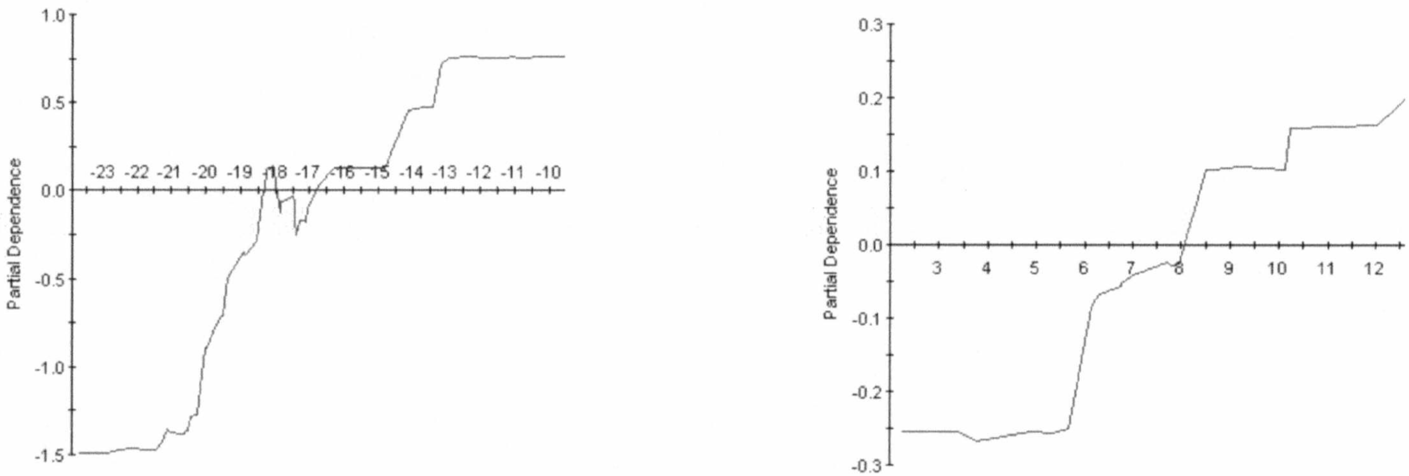
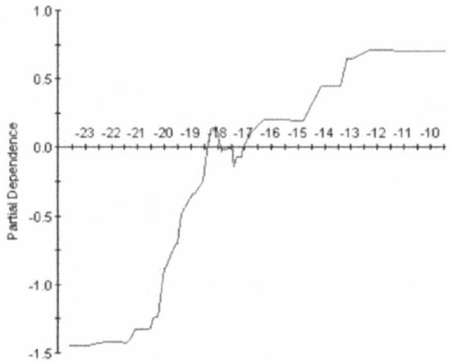
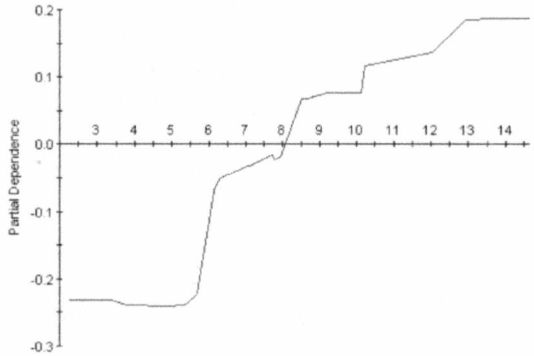


Figure 3.6. Partial dependence plots of *T. canis* presence for model four described by AICc and analysed using TreeNet. Negative values for partial dependence indicate avoidance and postive values indicate preference in relative units. Suggested habitat thresholds are indicated at Y axis intercept point. (A. Mean annual temperature for January (Celsius), B. Wolf density (Wolves per 1000 kilometers squared).

A) Mean annual temperature for January (Celsius)



B) Wolf density (Wolves per 1000 kilometers squared)



C) Mean annual temperature for August (Celsius)

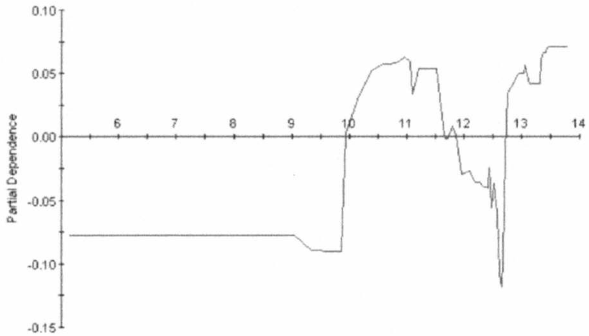


Figure 3.7. Partial dependence plots of *T. canis* presence for model seven described by AICc and analysed using TreeNet. Negative values for partial dependence indicate avoidance and postive values indicate preference in relative units. Suggested habitat thresholds are indicated at Y axis intercept point. (A. Mean annual temperature for January (Celsius), B. Wolf density (Wolves per 1000 kilometers squared), C. Mean annual temperature for August (Celsius).

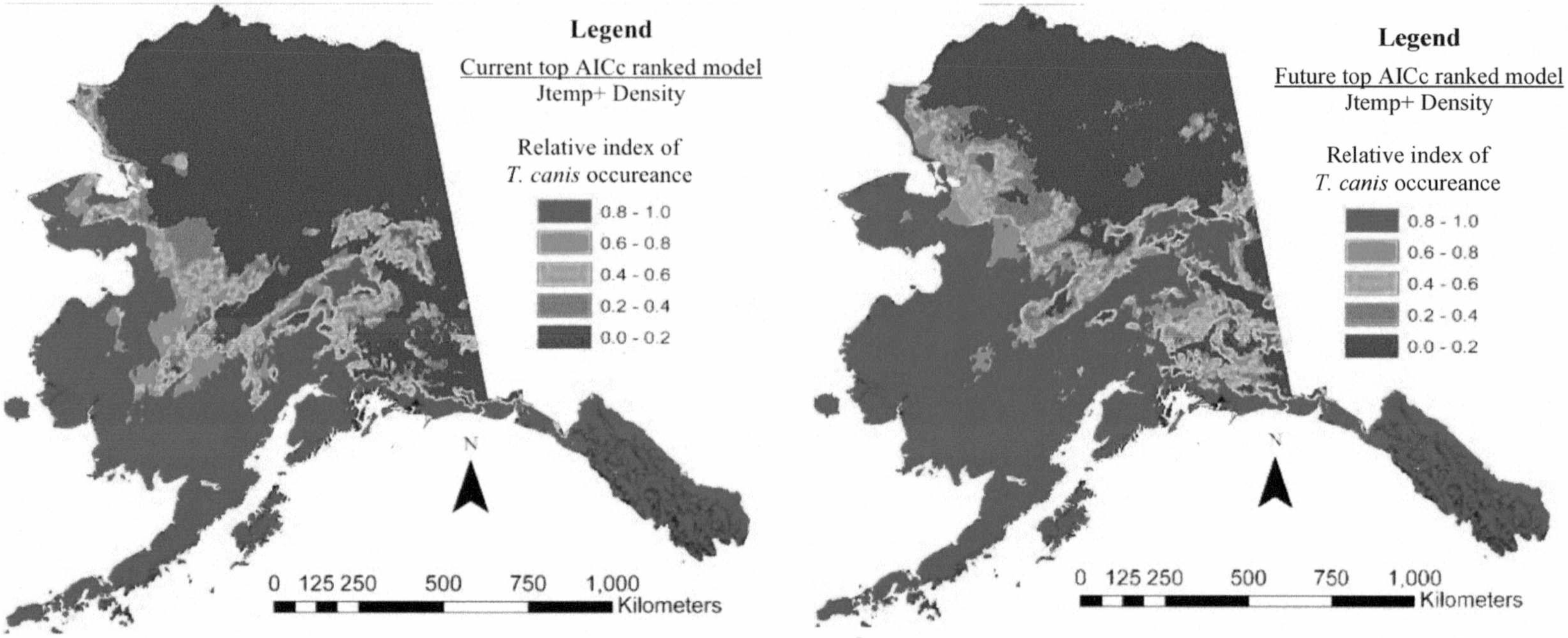


Figure 3.8. Relative index of occurrence for *T. canis* within the state of Alaska based on model four, the top competing model ranked by AICc. Future climatic models include mean annual temperature and precipitation averages for 2029 to 2039. Red colored regions indicate areas of high relative index of occurrence, while blue areas denote low relative index of occurrence. Relative index of occurrences represent an odd ratios which describes the strength of association.

Thesis Conclusions

Trichodectes canis was first documented on Alaska gray wolves in 1981 (Schwartz *et al.*, 1983; Taylor and Spraker, 1983). Prior to this study, it was unknown why *T. canis* was not observed within Alaska gray wolves until the 1980s, and why wolves of the Susitna River Valley and Kenai Peninsula exhibited higher prevalence of moderate to severe pediculosis (lice infestation) as compared to wolves north of the Alaska Range near Fairbanks and the Upper Kuskokwim River (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). Two hypotheses were proposed to explain why *T. canis* was not observed in Alaska until the 1980s. First, observed symptomatic wolves could be predisposed to pediculosis, whereas mild infestations outside the observed infestation region are undetected by visual inspection. That hypothesis assumes that *T. canis* is native to Alaska. A second possible explanation is that *T. canis* is an invasive ectoparasite, and Alaska wolves outside the infestation region do not harbor lice. My study assessed the current distribution of *T. canis* within Alaska and tested the hypothesis that *T. canis* occurs naturally in Alaska wolves and is present in low densities in areas not characterized by symptomatic wolves.

To accurately detect mild pediculosis outside of the known infestation area, my study developed a hide dissolution method utilizing potassium hydroxide (KOH). Until recently, detection of *T. canis* on Alaska gray wolves was based upon visual observation of lice, presence of characteristic hair damage suggestive of pediculosis, and histopathology of representative skin tissue. Although severe to moderate pediculosis can typically be detected by trained visual examination and histopathology, occult infestations can be easily overlooked (Clayton and Drown, 2001; Watson *et al.,* 1997). Hide dissolution of the entire host integument tends to be a more precise method of lice detection as compared to visual or histopathology examination used prior to this study (Watson *et al.,* 1997; Clayton and Drown, 2001). However, digestion of the entire host integument is a time-consuming process. Our objective was to determine optimal sample locations for *T. canis* detection within Alaska gray wolves utilizing KOH hide dissolution.

Two types of samples were investigated, a 100 cm^2 hide sample from selected areas of the pelt and large hide samples representing one-fourth of a hide split down the midline from the cranial to the caudal end of the wolf (Figure 1.1; Figure 1.2). The highest mean proportion of lice for the large hide samples was documented within the caudal region, which includes the groin and rump of the hide (Table 1.1). All examined cases of mild pediculosis were successfully identified utilizing the caudal region, while hide sections cranial of the axial plane failed to detect *T. canis* presence in some cases (Table 1.2). Our study suggests that the optimal sampling location for *T. canis* on Alaska gray wolves is the most caudal region of the hide, comprising the sacral area and groin. However, the practical application of KOH hide dissolution of the larger hide sections may be limited due to the reduction of pelt market value. Requiring the submission of large hide samples may not be acceptable for hunters or trappers. In comparison, the 100 cm^2 samples from the groin possessed a relatively low false-negative rate as compared to samples from the back and mean lice proportion was not significantly different. The groin also possesses low market value and requesting this region for lice surveillance could be acceptable by hunters and trappers.

Utilizing KOH hide dissolution, our study examined wolf hides outside of the known distribution of the louse to test the hypothesis that *T. canis* occurs naturally in Alaska wolves. Mild pediculosis was not detected outside of the known symptomatic infestation zone, which includes Southcentral Alaska and immediately north of the Alaska Range (Figure 2.1). Based on the current distribution, our study suggests that *T. canis* is a recently introduced ectoparasite of Alaska wolves. The high prevalence of symptomatic Alaska wolves is likely due to the novel nature of *T. canis*.

My study assessed potential ecological correlates associated with *T. canis* presence and absence within Alaska wolves, and tested the hypothesis that the distribution of *T. canis* is temperature-dependent and constrained by low wolf densities. Utilizing relative index of occurrence, current and future realized niche models were developed for *T. canis* in Alaska. Similar to other species of chewing lice (Ash, 1960; Moyer and Wagenbach, 1995; James *et al.,* 1998), temperature has been suggested as an important limiting factor for *T. canis* in Alaska. Temperature thresholds for the sheep louse *Bovicola ovis* were indicated at daily mean temperatures of 11.5°C and maximum daily mean temperatures below 15°C (James *et al.,* 1998). In comparison, *T. canis* models indicate a temperature threshold between -19.2°C to -18.3°C on free-ranging Alaska wolves (Woldstad *et al.,* Chapter 3). Variations in ambient temperature are also important determining factors of several insect species distribution and range expansion (Crozier, 2003; Desender *et al.,* 2002; Battisti *et al.,* 2005). The northern range expansion of *Atalopedes campestris* is positively associated with colonized areas which have exhibited a 3°C rise in January minimum temperature since the 1950s (Crozier, 2003). Over the last century Alaska has experienced state-wide increases in mean annual temperatures (Stafford *et al.,* 2002; Wendler and Shulski, 2009). It is possible that as Alaska experiences warmer weather events and climatic conditions, *T. canis* could continue to expand its distribution into Southwestern, Southeastern, and Northern Alaska. In addition to climatic factors, *T. canis* abundance and transmission rates within Alaska wolves are possibly influenced by wolf dispersal rates, mortality, social structure, prey availability, and wolf densities (Krasnov *et al.,* 2002; Fuller *et al.,* 2003; Whiteman and Parker, 2004). *Trichodectes canis* presence was found to be positively associated with wolf densities greater than eight wolves per 1000 km^2 (Figure 3.6).

The results of my study are critical to the development of successful management strategies for *T. canis* as an invasive ectoparasite of Alaska wolves. In April 2005, Alaska Department of Fish and Game (ADF&G) initiated an experimental mitigation management strategy for *T. canis* south of Fairbanks. Wolf packs are treated for pediculosis utilizing multi-dose, remotely delivered ivermectin-containing meat baits dropped biweekly from May to August at den and rendezvous sites (Gardner and

Beckmen, 2007; Gardner and Beckmen, 2008). Successful treatment of wolf packs was determined utilizing KOH hide dissolution for harvested wolves and at least one pup collected from treated packs for a minimum of two years post-treatment. Current data indicates that this treatment regime was successful in eliminating *T. canis* in treated packs within the Tanana River Flats south of Fairbanks (Gardner and Beckmen, 2008; ADF&G unpublished data).

The development of precise sampling strategies is critical to the success of the ADF&G active management for *T. canis*. If mild cases of pediculosis escape detection and subsequent treatment, managed wolf packs will become reinfested and would spread *T. canis* to adjacent packs. In addition to the Fairbanks management area, it is recommended that a monitoring program for *T. canis* be conducted across Alaska to establish transmission rates between wolf packs, determine the effects of pediculosis on productivity and survival rates of Alaska gray wolves, and monitor the distribution and rate of spread of this invasive ectoparasite of Alaska wolves. Currently, *T. canis* has not been documented within Western and Southeastern Alaska. However, realized niche models indicate a relatively high index of occurrence within these areas. It is possible that *T. canis* could expand its range from the North Fork of the Kuskokwim River southwest along the low elevation river corridors of the Yukon and Kuskokwim Rivers into Southwestern Alaska (Woldstad *et al.,* Chapter 2). Establishing a monitoring program and early treatment regime within Western Alaska is critical to the effective management of *T. canis*.

My study currently marks the northernmost documented case of *T. canis* in North America wolves in the Yukon-Charley Rivers National Preserve (Woldstad *et al.,* Chapter 2). However, the northern limit of *T. canis* within North America is not well defined. South of the known latitudes of lice in Alaska, *T. canis* has been documented in British Columbia (Hopkins, 1960), the Manitoba-Saskatchewan border (Mech *et al.,* 1985), and Ontario (Judd, 1954). It is unknown if *T. canis* is present within Nunavut, Northwest Territories, or the Yukon Territory. While *T. canis* potential distribution maps have been created for future Alaska climatic conditions, continued research and monitoring of *T. canis* distribution within Alaska as well as Canada is required to improve present model estimations. In addition to continued *T. canis* surveillance, it is recommended that field and laboratory research be conducted to evaluate potential climatic constraints.

Long-term effects of *T. canis* infestation on wild Alaska wolf populations are currently unknown. Typical clinical signs of severe to moderate pediculosis include matting of the pelage from sebaceous secretions, hair loss (alopecia) of the guard hairs and under fur, and potential self inflicted trauma often causing inflammation, lesions, and infected sores (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). It is possible that moderate to severe pediculosis could increase the energetic costs of thermoregulation and could potentially affect fecundity and survival rates of Alaska wolves. Currently it is unknown how *T.*

canis could affect individual fitness of healthy adult wolves or pups. Field and laboratory research is recommended to determine the energetic costs of pediculosis and the potential associated pathology.

In addition to the intrinsic value of the stability and health of Alaska gray wolf populations, pediculosis could also have significant economic impact in terms of the extrinsic value of wolves as a furbearer. Louse-infested wolves often display symptoms of pediculosis between the shoulder blades, including visually apparent matting and alopecia (Schwartz *et al.,* 1983; Taylor and Spraker *et al.,* 1983). Hair breakage and damage can descend from the shoulders down the back, destroying the mane and the value of the fur. The mane of the wolf, which spans from the neck down to the shoulders and towards the center of the back, possesses the longer, more erectile guard hairs (Mech 1970). This area is of particular value in terms of traditional clothing such as winter parka ruffs. Reduction of furbearer value due to *T. canis* infestation could potentially reduce supplemental income from wolf pelt sales and impact the mixed subsistence-cash economies of rural Alaska. Alaska gray wolves also provided important economic benefits in associated tourism (Fritts *et al.,* 2003). *Trichodectes canis* can reduce wildlife viewing quality, as infested wolves may exhibit overall poor condition and visually apparent signs of pediculosis such as frequent scratching and rubbing (Schwartz *et al.,* 1983; Taylor and Spraker, 1983). It is unknown how *T. canis* could impact associated tourism markets within infested national parks and wilderness areas of Alaska such as Denali National Park.

Although wolves provide monetary benefits in terms of its fur value, it is important to note the cultural significance of consumptive uses of wolves. Personal use items made from wolves include: wolf parka ruffs, tanned skins used as gifts during traditional potlatches, ceremonial clothing, and traditional native art materials. Consumptive uses of wolves are an important aspect of traditional Alaskan culture (Phillip 2006, Fritts *et al.,* 2003). Within many areas, such as the Yukon-Kuskokwim Delta, locally obtained wolf ruffs are highly prized for traditional parka trim and are preferred to commercial hides (Phillip 2006, Fritts *et al.,* 2003). Southwestern Alaska, including the Yukon-Kuskokwim Delta, possesses a relatively high index of *T. canis* occurrence from current and future realized niche models (Woldstad *et al.,* Chapter 3). It is likely that moderate to severe pediculosis could adversely affect the ability of rural Alaska resident to obtain culturally important consumptive goods.

In conclusion, my study provided the first critical assessment of *T. canis* as an invasive ectoparasite of Alaska wolves. I developed potential sampling methodologies, including recommendations that the 100-cm^2 groin hide sample be utilized for *T. canis* surveillance in trapper- and hunter-harvested wolves utilizing KOH hide dissolution. My study also assessed potential ecological correlates of *T. canis* presence; finding potential ecological thresholds of wolf densities greater than eight wolves per 1000 km^2 and mean annual January temperatures warmer than -19°C. I also developed realized niche models for current and future climatic conditions, assessing potential areas at risk for *T. canis* range expansion. Currently my study has documented Yukon-Charley Rivers National Preserve as the northernmost case of *T. canis* within North America wolves the (Woldstad *et al.*, Chapter 2). The results of this study are the first critical step in the development of successful management strategies for *T. canis* as an invasive ectoparasite of Alaska wolves.

Literature Cited

ASH, J. S., 1960. A study of the Mallophaga of birds with particular reference to their ecology. Ibis 102: 93–110.

BATTISTI, A., M. STASTNY, S. NETHERÈR , C. ROBINET, A. SCHOPF, A. ROQUES, AND S. LARSSON. 2005. Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. Ecological Applications 15: 2084–2096.

CLAYTON, D. H., AND D. M. DROWN. 2001. Critical Evaluation of five methods for quantifying chewing lice (*Insecta: Phthiraptera*). Journal of Parasitology 86: 1291–1300.

CROZIER, L. 2003. Winter warming facilitates range expansion: cold tolerance of the butterfly *Atalopedes campestris*. Oecologia 135: 648–656.

DESENDER, K., A. CASALE, L. BAERT, J. MAELFAIT, AND P. VERDYCK. 2002. *Calleida migratoria* casale, new species (Coleoptera: Carabidae), a newly introduced ground beetle in the Galapagos Islands, Ecuador. The Coleopterists Bulletin 56: 71–78.

FRITTS, S. H., R. O. STEPHENSON, R. D. HAYES, AND L. BOITANI. 2003. Wolves and humans. *In* Wolves: behavior, ecology, and conservation, L. D. Mech and Boitani L. (eds). University of Chicago Press, pp. 289–316.

FULLER, T. K., L. D. MECH, AND J. F. COCHRANE. 2003. Wolf population dynamics. *In* Wolves: behavior, ecology, and conservation, L. D. Mech and Boitani L. (eds). University of Chicago Press, 161–191.

GARDNER, C., AND K. BECKMEN. 2007. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1st July 2006–June 2007. Federal Aid in Wildlife Restoration. Grant W–33–5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife Conservation. Juneau, Alaska, USA.

__________, AND __________. 2008. Evaluating methods to control an infestation by the dog louse in gray wolves. Research Annual Performance Report. 1st July 2007–June 2008. Federal Aid in Wildlife Restoration. Grant W–33–5. Project 14.25. Alaska Debarment of Fish and Game Division of Wildlife conservation.

HOPKINS, G. H. E. 1960. Notes on some Mallophaga from mammals. Bulletin of the British Museum (Natural History) Entomology 10: 75–95.

JAMES, P. J., R. D. MOON, AND D. R. BROWN. 1998. Seasonal dynamics and variation among sheep in densities of sheep biting louse, *Bovicola ovis*. International Journal for Parasitology 28: 283–292.

JUDD, W. 1954. Some Records of Ectoparasitic Acarina and Insecta from Mammals in Ontario. The Journal of Parasitology 40: 483–484.

KRASNOV, B., KHOKHLOVA I., AND G, SHENBROT. 2002. The effect of host density on ectoparasite distribution: and example of a rodent parasitized by fleas. Ecology 83: 164–175.

MECH, D. L. 1970. The Wolf's Wanderings. *In* The Wolf: The Ecology and Behaviors of an Endangered Species, D. L. Mech (ed.). University of Minnesota Press, pp. 149–167.

__________, R. P. THIEL, S. H. FRITTS, AND W. E. BERG. 1985. Presence and effects of the dog louse *Trichodectes canis* (Mallophaga, Trichodectidae) on wolves and coyotes from Minnesota and Wisconsin. American Midland Naturalist 114: 404–405.

MOYER, B. R., AND G. E. WAGENBACH. 1995. Sunning by Black Noddies (*Anous minutus*) May Kill Chewing Lice (*Quadraceps hopkinsi*). The Auk. 112: 1073–1077.

PHILLIP, P. 2006. Unit 18 wolf management report. *In* Wolf management report of survey and inventory activities, P. Harper (eds.). 1 July 2002–30 June 2005. Alaska Department of Fish and Game. Project 14.0. Juneau, Alaska, USA, pp. 126–135.

SCHWARTZ, C. C., R. STEPHENSON, AND N. WILSON. 1983. *Trichodectes canis* on the gray wolf and coyote on Kenai Peninsula, Alaska. Journal of Wildlife Diseases 19: 372–373.

STAFFORD, J. M., G. WENDLER, AND J. CURTIS. 2002. Temperature and precipitation of Alaska: 50 year trend analysis. Theoretical and Applied Climatology, 67: 33–44.

TAYLOR, W. P., JR., AND T. H. SPRAKER. 1983. Management of a biting louse infestation in a free-ranging wolf population. *In* Proceedings: Annual Proceedings of the American Association of Zoo Veterinarians, M. E. Fowler (ed.). Tampa, Florida, pp. 40–41.

WATSON, D. W., J. E. LLOYD, AND E. KUMAR. 1997. Density and distribution of cattle lice (Phthiraptera: Haematopinidae, Linognathidae, Trichodectidae) on six steers. Veterinary Parasitology 69: 283–296.

WENDLER, G. AND SHULSKI, M. 2009. A Century of Climate Change for Fairbanks, Alaska. – Arctic 62: 295–300.

WHITEMAN, N. K. AND PARKER, P. G. 2004. Effects of host sociality on ectoparasite population biology. Journal of Parasitology 90: 939–947.